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ERRATUM

DISCOVERY REPORTS, VOL. XIII, 1936. FORAMINIFERA. PART IV. ADDITIONAL RECORDS FROM THE WEDDELL SEA SECTOR.

On pp. 21 and 27 and explanation of Plate I, figs. 10 and 11, for *Thurammina corrugata*, sp.n., substitute *Thurammina brucei*, sp.n. (after the late Dr W. S. Bruce, leader of the Scottish National Antarctic Expedition, 1902–4).

The specific name *corrugata* is preoccupied by *Thurammina corrugata*, Earland, 1934 (Discovery Reports, Vol. x, p. 70, No. 103, Plate II, figs. 15–18). The two species are distinct and not closely related.

=7

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by

Arthur Earland, F.R.M.S.

WITH A REPORT ON
SOME CRYSTALLINE COMPONENTS OF
THE WEDDELL SEA DEPOSITS

by

F. A. Bannister, M.A.
with CHEMICAL ANALYSES *by*
M. H. Hey, M.A., B.Sc.

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ARTHUR EARLAND, F.R.M.S.

With a Report on

SOME CRYSTALLINE COMPONENTS OF THE WEDDELL SEA DEPOSITS

By F. A. Bannister, M.A., with chemical analyses by M. H. Hey, M.A., B.Sc., Assistant Keepers in the Mineral Department of the British Museum (Natural History)

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FORAMINIFERA

PART IV. ADDITIONAL RECORDS FROM THE WEDDELL SEA SECTOR FROM MATERIAL OBTAINED BY THE S.Y. 'SCOTIA'

By Arthur Earland, F.R.M.S.

(Plate I; text-figs. 1, 2)

INTRODUCTORY NOTE

In February 1931, the R.R.S. 'William Scoresby' ran a line of stations, WS 542–55, in the Weddell Sea between 10 and 20° W, reaching 68° 53′ S at St. WS 552. The results were mainly hydrographical, but soundings were obtained at Sts. 552, 553, 555, the Foraminifera from which were included in the Discovery Report (1934, X, pp. 1–208, pls. i–x) on *The Falklands Sector of the Antarctic (excluding South Georgia)*.

Apart from these scanty records, our knowledge of the bottom deposits of the Weddell Sea rests on the material brought back by the late Dr W. S. Bruce, of the Scottish National Antarctic Expedition in the S.Y. 'Scotia', 1902–4. In the course of her cruise the 'Scotia' penetrated to the Coats Land coast of the Antarctic Continent in 74° 01′ S, and made several lines of stations traversing the Weddell Sea between the meridians 10° and 45° W. A report on the nature of the deep sea deposits was made by Mr Harvey Pirie (P. 1905, DSD), and the Foraminifera were described by the late F. G. Pearcey (P. 1914, SNA).

When I was preparing Part III of the Report on Discovery Foraminifera, it became a matter of some importance to examine the new types described by Pearcey. But in spite of inquiry pursued in all likely quarters these were not discoverable (see E, 1934, A, p. 12), a fact which now seems even more regrettable than I then regarded it.

While making inquiry on the subject at the Royal Scottish Museum, Edinburgh, where the Bruce collections are preserved, I learned from Dr A. C. Stephen that the Museum still had a quantity of sounding deposits brought back by the 'Scotia'. As my Discovery report was already in proof nothing could then be done in the matter, but after publication it seemed desirable if possible to reconstitute the missing types, and with the Director's approval, the whole of the material was placed at my disposal. It included deposits from three stations, 118, 451, 459, which lie outside the Antarctic convergence line. These are marked with an asterisk in the subjoined list of material received. They have been disregarded in the preparation of the following report, which is confined to stations within the convergence. The letter P in the list indicates a station at which Pearcey recorded the presence of Foraminifera, but it is not known whether he examined material from the other stations also. From the fact that the stations not

marked P proved the poorest and most refractory of the deposits, it seems probable that Pearcey sampled them and did not proceed with their examination. Further details of the material on which I worked will be found on pp. 16–21.

	Deposit No.	St.	Locality		Depth fathoms	Date	Description of deposit in Station Log
P*	2	118	Stanley Harbour	Falkland Islands	$3\frac{1}{4}$[1]	14. i. 03	Mud
	8	226	64° 18′ S	23° 9′ W	2739	17. ii. 03	Glacial clay
	11	280	68° 40′ S	30° 18′ W	2511	2. iii. 03	Glacial clay
	12	282	68° 31′ S	32° 8′ W	2452	3. iii. 03	Glacial clay
P	13	286	68° 11′ S	34° 17′ W	2488	5. iii. 03	Glacial clay
	14	290	67° 39′ S	36° 10′ W	2500	6. iii. 03	Glacial mud
P	15	295	66° 40′ S	40° 35′ W	2425	10. iii. 03	Glacial mud
P	16	300	65° 29′ S	44° 6′ W	2500	12. iii. 03	Glacial clay
P	17	301	64° 48′ S	44° 26′ W	2485	13. iii. 03	Glacial mud and boulders
	18	303	64° 24′ S	43° 18′ W	2547	14. iii. 03	Glacial mud
	19	309	63° 51′ S	41° 50′ W	2550	16. iii. 03	Glacial clay
	20	312	62° 56′ S	42° 20′ W	1956	17. iii. 03	Glacial mud
P	21	313	62° 10′ S	41° 20′ W	1775	18. iii. 03	Glacial mud or sand and boulders
P	27[2]	338	59° 23′ S	49° 8′ W	2180	28. xi. 03	Diatom ooze and volcanic sand
	28	342	56° 54′ S	56° 24′ W	1946	30. xi. 03	*Globigerina* ooze
P	30	387	65° 59′ S	33° 6′ W	2625	26. ii. 04	Glacial clay
	31	391	66° 14′ S	31° 18′ W	2630	27. ii. 04	Glacial clay
	32	394	66° 43′ S	27° 55′ W	2685	28. ii. 04	Glacial clay
	33	406	72° 18′ S	17° 59′ W	1131	3. iii. 04	Glacial mud
P	37	416	71° 22′ S	18° 15′ W	2370	17. iii. 04	Glacial mud
P	38	417	71° 22′ S	16° 34′ W	1410	18. iii. 04	Glacial mud and stones
P	39	418	71° 32′ S	17° 15′ W	1221	19. iii. 04	Glacial mud and rocks
P	41	421	68° 32′ S	10° 52′ W	2487	22. iii. 04	Glacial clay
	42	422	68° 32′ S	12° 49′ W	2660	23. iii. 04	Glacial clay
	43	428	66° 57′ S	11° 13′ W	2715	27. iii. 04	Glacial clay
	44	432A	61° 21′ S	13° 2′ W	2764	30. iii. 04	Glacial clay
P	45	438	56° 58′ S	10° 3′ W	2518	3. iv. 04	Diatom ooze and volcanic sand
P	46	447	51° 7′ S	9° 31′ W	2103	9. iv. 04	Diatom ooze and rock
P*	47	451	48° 6′ S	10° 6′ W	1742	13. iv. 04	Pebbles and diatom to *Globigerina* ooze
P*	49	459	41° 30′ S	9° 55′ W	1998	20. iv. 04	*Globigerina* ooze

[1] Depth in Station Log, $2\frac{1}{4}$ fathoms. [2] No. 26B in Pearcey's list.

In addition to the stations marked P in the foregoing list, Pearcey recorded results from three stations within the convergence from which I received no material:

Deposit No.	St.	Locality		Depth fathoms	Date	Description of deposit in Station Log
14A	291	67° 33′ S	36° 35′ W	2500	7. iii. 03	Glacial mud and boulders
26A	337A	59° 46′ S	48° 02′ W	2110	28. xi. 03	Glacial mud to diatom ooze
40	420	69° 33′ S	15° 19′ W	2620	21. iii. 04	Glacial clay

The absence of material from St. 420 is particularly regrettable, as Pearcey records that "a fair supply" was available, and that he prepared two pounds of the deposit, including trawl washings, for examination. Of the eleven new species and varieties

which he described, no less than eight were recorded from this station, seven of them occurring nowhere else. His three remaining types came from St. 346 on the Burdwood Bank, outside the convergence line. As a result of this lack of material from St. 420, the particular object which I had in view in undertaking the examination of the deposits remains unfulfilled, hardly any of Pearcey's types having been identified with certainty at the other stations. Otherwise, however, large additions have been made to the faunal list of the Weddell Sea, 229 species and varieties being listed in the following report, including four new species, as against 138 species and varieties recorded by Pearcey from stations within the Antarctic convergence. The discrepancy is even greater than these numbers suggest, for included in Pearcey's list of 138 species are the following fifty-two species which I did not meet with in my examination of material, although a few of them have been tentatively identified as synonyms of my records.

**Biloculina ringens* (Lamarck) (see No. 3)
**Spiroloculina limbata*, d'Orbigny
Miliolina bucculenta, Brady
**Miliolina bucculenta* var. *placentiformis*, Brady
Astrorhiza crassatina, Brady
**Syringammina minuta*, sp.n.
**Rhabdammina cornuta*, Brady
**Rhizammina indivisa*, Brady
R. algaeformis, Brady
**Sorosphaera confusa*, Brady
Saccammina socialis, Brady
**Pelosina arborescens*, sp.n.
**Technitella raphanus*, Brady
**T. asciformis*, sp.n.
**Webbinella hemisphaerica* (Jones, Parker and Brady)
**Crithionina pisum*, Goës, var. *hispida*, Flint
**Hyperammina subnodosa*, Brady
**Aschemonella ramuliformis*, Brady
**Reophax adunca*, Brady
**R. robustus*, sp.n.
**Hormosina irregularis*, sp.n.
**Haplophragmoides umbilicatum*, sp.n.
**Thurammina favosa*, Flint, var. *reticulata*, var. nov. (see No. 30)
Trochammina turbinata (Brady) (see No. 74)
**Globotextularia anceps* (Brady)
Spiroplecta biformis, Parker and Jones
**Textularia conica*, d'Orbigny
**Textularia concava* (Karrer)
Gaudryina pseudofiliformis, Cushman (see No. 107)
**Ehrenbergina serrata*, Reuss (see No. 123)
**E. pupa* (d'Orbigny)
Lagena semistriata, Williamson
**L. multicosta* (Karrer)
**L. torquata*, Brady
L. feildeniana, Brady
**L. acuta* (Reuss)
**L. quinquelatera*, Brady
**L. auriculata*, Brady
**Nodosaria roemeri*, Neugeboren
**N. perversa*, Schwager
**Polymorphina gibba*, d'Orbigny
**Uvigerina brunnensis*, Karrer
**U. aculeata*, d'Orbigny
Globigerina dubia, Egger (see No. 203)
Pullenia obliquiloculata, Parker and Jones
**Truncatulina dutemplei* (d'Orbigny)
T. tenuimargo, Brady (see No. 210)
**Anomalina polymorpha*, Costa
**Globoratalia* (*Pulvinulina*) *canariensis* (d'Orbigny)
**Globorotalia* (*Pulvinulina*) *truncatulinoides* (d'Orbigny)
**Epistomina* (*Pulvinulina*) *elegans* (d'Orbigny)
Nonion umbilicatulus (Montagu)

The majority of these missing species (marked with an asterisk) were recorded from St. 420, off Coats Land, from which I had no material, or St. 342 in the Scotia Sea, where the sample received was too small for examination. It would therefore seem that Pearcey's examination of the Scotia material was rather superficial. If it had been carried through exhaustively his paper, which was the first in the Antarctic field, would have

formed a solid basis for future work, and he would have anticipated several genera and a large number of species which have since been described from Antarctic material.

CHARACTERS OF THE MATERIAL RECEIVED

Most of the deposits received by me were in their original containers which incidentally throw some light on the financial stringency of the expedition, and the ingenuity with which Bruce adapted his resources to his work. The containers were principally bottles and jars in which provisions had been preserved, many still bearing the original labels. Except from the two stations 313 and 417, the material consisted only of cores from a sounding machine (? Sigsbee tube), and had originally been preserved in spirit. Their condition varied, some being in perfect preservation after thirty years in store, while others, owing to defective corks, had dried up. In addition to a sounding, each of the stations 313 and 417 also yielded a jar of washings from the trawl, and from these the majority of the larger species have been recorded.

Every container had a label in pencil inside and a similar label in ink on the outside. The inner label was often so embedded in the material, especially when the sample was dry, that it was only recoverable in fragments, while the outer label was generally more or less obliterated by dirt and wear. From a combination of the two it was, however, possible to identify everything with certainty by means of the Station Log (B. 1918, SLS), even when only fragments of the labels were preserved. Very few of the labels bore the station number, but only a low serial "deposit" number, ranging between 2 (St. 118) and 49 (St. 459). But for the fact that Pearcey quotes these "deposit" numbers as well as the station numbers, identification would have been less certain in some cases, as for some unknown reason Bruce did not record these "deposit" numbers in his Station Log. Presumably no bottom samples were preserved from the hundreds of other stations, although the nature of the deposit is occasionally described in the log.

No shallow-water material was received from within the Antarctic convergence. With the exception of Sts. 406, 417 and 418, which are situated on the continental slope of Coats Land in depths of 1131–1410 fathoms, all the soundings are from the abyssal plain of the Scotia and Weddell Seas between 1775 and 2764 fathoms. Among the samples are a few *Globigerina* and diatom oozes which call for no special mention. With these exceptions the soundings are of a character previously unknown to me, and described by Bruce in his Station Log as "Glacial Mud" and "Glacial Clay", the terms being used without much apparent discrimination. Pirie, on the other hand, divides these deposits into "Blue Mud" and "Blue Mud approximating to Red Clay". The "Blue Mud" he regards as a terrigenous deposit extending from the Antarctic coast-line to about 60° S, and in his chart he shows it as a uniform belt extending from Kemp Land in 60° E to 90° W in the Bellingshausen Sea. The "Blue Mud approximating to Red Clay" is shown on his chart as an elliptical area in the Biscoe and Weddell Seas to the north of the Blue Mud belt, extending from about 40° E to nearly 40° W, and lying between the Blue Mud and the circumpolar diatom ooze belt. The chart seems to be more or less empirical, for the few stations from which material was obtained (Sts. 226,

387, 391, 394, 432A) lie in the western end of this ellipse, and the remainder of it is probably an unknown quantity so far as bottom deposits are concerned.

As regards the foraminiferal fauna of the two deposits, there appears to be little difference between the Blue Mud and the Blue Mud approximating to Red Clay. The number both of species and specimens decreases enormously, as might be expected considering the greater depth and distance from the Antarctic coast-line, but setting aside the stations on the continental slope, where the foraminiferal fauna is abundant and varied as it usually is on such slopes, there are many stations in the Blue Mud area with approximately similar faunal lists to those of the stations in the area of the Blue Mud approximating to Red Clay.

Pirie's description of the two deposits is worth extracting, especially as he deals with the material from a mineralogical standpoint, while any remarks of mine are necessarily of a faunistic character.

Blue Mud. A typical specimen from the sounding tube has the following characteristics. It is of a greenish-grey or bluish-grey colour and is a coherent, moderately tough mud with a sufficiently clayey character to give it an unctuous feeling, but when rubbed between the finger tips one can always feel some gritty particles. When dried it is of a light grey colour and has a slightly clayey odour when breathed upon, and is capable of taking a lustrous polish when rubbed on the finger nail. There is never any smell of sulphuretted hydrogen as in many terrigenous muds. Of $CaCO_3$ there is in most cases none, but every now and again a certain amount occurs, varying from a mere trace up to 6 per cent. This is from the shells of Foraminifera.... Siliceous organisms are extremely rare; they may be entirely absent or there may be from a trace up to 1–2 per cent; and these are chiefly sponge spicules and fragments of Radiolaria, very rarely diatoms.

Mineral particles over 0·05 mm. in diameter form 10–20 per cent of the deposit; the majority are angular in shape but the larger fragments up to 2 or 3 mm. in diameter are generally sub-angular, and occasionally glacial striae may be detected on them. Quartz grains predominate largely, but a great variety of other minerals occurs. Glauconite is rare, being only found as casts in a few of the samples in which there are calcareous Foraminifera. Manganese is common as a thin pellicle over other mineral particles, and a few very small grains occur, but there are no nodules such as are found in the abyssal Red Clays.

The remainder of the deposit is made up of "fine washings". When examined microscopically this part is found to contain occasional fragments of siliceous organisms, and a small amount of true amorphous clayey matter, but it largely consists of minute mineral fragments under 0·05 mm. in size, the majority being probably between 0·02 and 0·005 mm. These represent the rock flour produced by the abrasive action of the Antarctic ice-sheets; this is carried out to sea partly in the ice of the icebergs, but no doubt largely also suspended in the water.... The trawl usually brought up a large quantity of mud and rocks. The latter vary in size from fine gravel up to boulders weighing over two cwts.... Some of the rock specimens have part of their surface clear and part coated with manganese; the shape indicates that the latter part must have been embedded in the mud, while the former projected out into the water.... It is noteworthy that only one whale's ear-bone was brought up. As whales are probably quite as numerous, if not more so, in this area than in the Red Clay area of the Pacific, the explanation can only be that they are buried by the rapidity with which this deposit is accumulating, as contrasted with the extreme slowness of the Red Clays....

Blue Mud approximating to Red Clay. The area...approaches Red Clay in many of its characters. The colour is more of a brownish-grey than the blue or green grey of the typical Blue Mud; it is more tenacious and clayey, and it is not so easily rubbed down for microscopic examination, but still much more easily than a typical Pacific or Atlantic Red Clay. The mineral particles average only about 3 per cent, of which a considerable number are of volcanic origin, but too much reliance cannot

be put on this for classification, as volcanic minerals are quite common in the Blue Muds. Ninety-five to ninety-eight per cent of the deposit consists of "fine washings", but it is the character of these that differentiates the deposit from the true Red Clays. There is certainly a considerably larger proportion of true clay than in the typical Blue Muds, but there is still a large amount of very minute land-derived mineral particles—the finest rock-flour—which has probably reached its destination largely in suspension. This area is, on the whole, about 200 fathoms deeper than the surrounding seas, but the difference in the character of the bottom is probably mainly accounted for by the comparative infrequency of bergs within this area, owing to the set of the currents. Here the rate of accumulation must be slower than in the Blue Mud area, but as not a single diatom was noted in any of the samples, one is precluded from the hypothesis that these get lost amidst the glacial detritus.

My own observations confirm most of the foregoing statements of Pirie, except that I see little difference between the two types of deposits beyond the much lesser proportion of mineral particles in the "Blue Mud approximating to Red Clay" samples. The foraminiferal fauna, as already mentioned, differs only in so far as might be expected from a greater depth and distance from the Antarctic coast-line. All the Weddell Sea soundings are very dissimilar in appearance and fauna from the Discovery deposits obtained in the Bellingshausen and Scotia Seas, which were as a rule easily cleaned and contained but a small percentage of clayey material. The Scotia material, on the other hand, was so firm and coherent that many of the cores retained their form in the bottles after thirty years in spirit, with the constant motion to which they have been subjected at intervals. Practically none of the samples could be cleaned directly on a sieve, but the material after slow drying generally broke down readily in hot water like a true clay, and was then washed easily on a silk sieve of 150 meshes to the linear inch. In many cases a second drying was necessary, and a few samples resisted even then, and were finally broken down in hot soda solution. A fraction of the material passing through the 150-mesh sieve was washed on 200-mesh silk as a final test for the presence of Radiolaria and diatoms. It was observed that when a sample had dried up in the bottle the layer in contact with the glass was refractory, and could not be broken down. Presumably some chemical reaction had been set up between the clay and the silica of the glass.

ABSENCE OF DIATOMS

The most striking distinction between the Weddell Sea material and the Discovery deposits from the Scotia and Bellingshausen Seas was the comparative absence of diatoms. The Discovery deposits, which were mostly from comparatively shallow water, contained diatoms in such abundance that they clogged the meshes of the sieves. In the Weddell Sea deposits, on the other hand, the sight of a single diatom was a noteworthy occurrence. Pirie refers to this in the foregoing extracts from his report, and elsewhere he remarks:

The relative amounts of diatoms in the surface waters and in the deposits form a marked contrast. Over the whole of the Blue Mud area of the Weddell Sea diatoms are extremely abundant in the surface waters; in the deposits on the other hand they are either entirely absent or present only in very small quantity. Their maximum occurrence on the bottom is in about 51° or 52° S (St. 447, *A.E.*) where, in the surface waters, they are comparatively infrequent. Can this absence in the Blue Mud be accounted for by the rapid accumulation of the glacial detritus hiding them? I think not—

for a reason that is given in the paragraph dealing with the Blue Mud resembling Red Clay. It is not a question of depth, for the difference is inconsiderable, about 2400–2700 fathoms for the Blue Mud and 2100–2500 fathoms for the Diatom Ooze; nor can it be accounted for by the surface currents; in the southern part of the Weddell Sea these are westerly, and in the northern part, about the boundary of the Blue Muds and Diatom Ooze, easterly. One is thrown back on the explanation tentatively put forward by Dr Philippi who found the same condition on the German Antarctic Expedition, viz. a northerly undercurrent which carries off the diatoms northward. Some indication of a strong undercurrent was got on the 'Scotia' while trawling; although this was south of 70° S lat., it may be a widespread condition, and possibly the study of the temperatures and salinities at different depths will throw further light on this question.

Again, referring to the diatom ooze found by the 'Scotia' along the meridian of 10° W, Pirie writes:

The band (of diatom ooze, *A.E.*) is here much wider (than the band between the Falklands and South Orkneys, *A.E.*) extending from about 48°–59° S. The transition from the Blue Mud on the southern edge is probably pretty sharp—in the Blue Mud from 61° 21′ S, 13° 2′ W (St. 432A, *A.E.*) there are no diatoms; in the ooze from 56° 58′ S, 10° 3′ W (St. 438, *A.E.*) they form 55 per cent of the whole deposit, in 51° 7′ S, 9° 31′ W (St. 447, *A.E.*) 2103 fathoms, the percentage rises to 70.

The theory of the removal of the diatoms by a northerly undercurrent, postulated by Philippi and accepted by Pirie, meets with the approval of Mr G. E. R. Deacon of the Discovery staff, to whom I am indebted for much useful information. He writes as follows:

The coldest stratum of the bottom water in the whole of the Southern Hemisphere, and in a great part of the Northern Hemisphere, has its origin chiefly in a cold current which sinks from the Continental Shelf in the south-west corner of the Weddell Sea. The distribution of temperature, salinity and oxygen in the bottom waters shows very clearly that the current from this source spreads eastwards round the whole of the Antarctic Continent, sending off northward current branches in the Atlantic, Indian and Pacific Oceans.

Since the bottom current from the Weddell Sea spreads over such a vast area, it is reasonable to suppose that, in the Weddell Sea itself, it will flow much more rapidly than it does elsewhere, and the freedom of the bottom deposits from diatom ooze and light muds may be due to a greater scouring of the bottom here than in any other region. Bruce speaks somewhere of a trawl being carried off the bottom, although more than the customary length of warp had been paid out.

There are several entries in the Scotia's Station Log which confirm Mr Deacon's statement of the force of the undercurrent. Gear was lost at several stations: at St. 416 it was "doubtful if trawl reached bottom"; at St. 418 "trawl did not touch bottom"; at St. 422, 2660 fathoms in 68° 32′ S, 12° 49′ W, Bruce remarks "Ross Deep obliterated; Ross obtained 4000 fathoms, no bottom, in 68° 34′ S, 12° 49′ W".

The chief difficulty in accepting this theory of the removal of diatoms by a northward current appears to me to lie in the fact that a current which removed the diatoms should also remove the clay and finer mineral particles, and deposit them to the northward. The diatoms might dissolve during their long journey, but the mineral particles should survive. But such detritus and clay does not form any large proportion of the diatom ooze belt in the north, where the inorganic material is described by Pirie as "mostly volcanic...the probability is that these particles have been carried from the South

Sandwich group by the prevalent westerly winds or by floating ice". So it seems that for the present we must accept the facts that the surface waters of the Weddell Sea are crowded with diatoms while very few are to be found in the bottom deposits, and leave the explanation for future investigators.

PACIFIC INFLUENCE IN THE WEDDELL SEA

As a result of the present investigation of the Scotia material some of the conclusions reached in the previous report (see A, pp. 12, 23–4) require modification. They were based on the evidence of the species listed by Pearcey, which seemed to show a rather scanty foraminiferal fauna almost entirely of a cosmopolitan cold-water description. This still holds, so far as the western and central areas of the Weddell Sea are concerned, as also the statement that Pearcey's rare and new species do not extend into the Scotia-Bellingshausen area. But the additions made to Pearcey's list indicate that the line of the Scotia arc can no longer be regarded as a limit to the distribution of species of Pacific origin.

I worked out the Scotia material in order of latitude, and for a long time the results were as expected and in accordance with Pearcey's records. Even the rich St. 313 with a long list of species yielded nothing unexpected. But as I got farther south I was surprised to record species which had not been found at stations farther to the north and west. At St. 286 in 2488 fathoms, almost in the centre of the southern Weddell Sea, three species of *Lagena* of distinctly Pacific origin were found, *L. sidebottomi* (No. 172), *L. desmophora* (No. 137) and *L. fimbriata* var. *occlusa* (No. 140). This station appears to be an outlier, as no warm-water species were detected at the stations to the east or west of it. Farther to the south, however, in the vicinity of the Coats Land coast, the evidence becomes more striking. St. 406, the most southerly station (in 72° 18′ S), in addition to yielding the only record of the genus *Miliammina* (No. 104) provided a single large specimen of *Gaudryina bradyi* (No. 111), an extension of 10° S latitude on previous records. St. 417, in 71° 22′ S, yielded quite a long list of species of Pacific origin, *Lagena quadrilatera* (No. 167), *L. fimbriata* var. *occlusa* (No. 140), *L. lamellata* (No. 155), *Cassidulina pacifica* (No. 122), *L. stelligera* var. *eccentrica* (No. 176), *Polymorphina extensa* (No. 197), *Nodosaria raphanistrum* var. (No. 185), and many other species, including *Globigerina bulloides* (No. 199), not to be expected in such a high latitude. This station represents the acme of development of warm-water species, and it is curious that the closely adjacent stations, 416 and 418, show little evidence of Pacific influence, which also diminishes as we go northwards away from the Antarctic coastline; St. 421, in 68° 32′ S, yielded several species unexpected in such latitude, but the only distinctly Pacific forms were *Lagena quadrilatera* (No. 167), *L. stelligera* var. *eccentrica* (No. 176), and *L. foveolata* var. *paradoxa* (No. 143). St. 422, in approximately the same latitude, gave no evidence whatever of warm-water influence, nor did St. 428 (66° 57′ S), St. 432A (61° 21′ S), or St. 438 (56° 58′ S). The most northerly station within the convergence, St. 447 in 51° 7′ S, gives very little indication of warm-water influence beyond the reappearance of *Globigerina bulloides* (No. 199), the specimens

being smaller than those found in the vicinity of Coats Land. Passing northwards on the same meridian of about 10° W, and outside the convergence at St. 451,[1] we begin to get a typical South Atlantic *Globigerina*-ooze fauna, the only Pacific form noted being *Bolivina cincta*, H.-A. and E. (see F 154, SG 183, A 280). The most northern station worked over was St. 459[1] (41° 30′ S, 9° 55′ W), 1998 fathoms, a typical South Atlantic *Globigerina* ooze which furnished a long list of species including many forms of Pacific origin, as might be expected from a station in the path of the West Wind Drift.

The occurrence of these southern and Pacific species in the far south, near the Antarctic coast-line, puzzled me greatly, and at one time I thought that all my theories of Antarctic distribution were to be proved incorrect. It was therefore gratifying to learn from Mr G. E. R. Deacon that there was hydrographical evidence of an inflow of Pacific water into the Weddell Sea, in the form of a mid-water current which on reaching the Antarctic coast-line was diverted to the west. From the records of the stations along the meridian of 10° W, it would seem that this current must make its entry to the east of that meridian, and its maximum influence is felt on the bottom edge of the continental shelf (St. 417). Presumably it then follows the unknown edge of the continent into the inner extension of the Weddell Sea, an area from which no material has been obtained, and is there lost in the cold Weddell Sea current. The outlying St. 286 may represent a diversion of the current, but its influence is slight, and it is not to be traced at the adjoining stations, 280, 282, 290 and 291, or in the line of stations 295–313, running north-west to the South Orkney Islands.

FOSSILS

At St. 406, off the coast of Coats Land (72° 18′ S, 17° 59′ W) in 1131 fathoms, and at St. 416, farther off shore (71° 22′ S, 18° 15′ W) in 2370 fathoms, a few minute fossils were found which are of interest as proof of the existence of Tertiary strata on the adjacent mainland. At St. 406 a single specimen of a calcareous alga (*Dactylopora*) was found. Professor J. Pia of Vienna was good enough to examine it when working recently at the British Museum (Natural History), and identified the specimen as *Neomeris* sp., cf. *N. annulus* (Parker and Jones) (Ann. Mag. Nat. Hist. (3), v, 1860, p. 474). The specimen differs from the type in the small size of the pores on the inner edge. Professor Pia informed me that although an unquestionable fossil it was of no value as a zone marker, the species having a range from Eocene to Recent in warm seas.

At the same station and also at St. 416, a little farther from the coast, a few minute Foraminifera were found which Dr W. A. Macfadyen of Baghdad has kindly examined. He reports as follows:

[1] These stations, 451 and 459, were worked out, but being outside the convergence are not included in this report.

A PROVISIONAL NOTE ON FOSSIL FORAMINIFERA DREDGED FROM THE WEDDELL SEA

By W. A. MACFADYEN, M.C., Ph.D.

Eight specimens were kindly sent to me for study, by Mr Arthur Earland. Nos. I, II and III (the last two mounted in a transparent medium), were dredged at "Scotia" St. 406, 72° 18′ S, 17° 59′ W, in 1131 fathoms; nos. IV–VIII at St. 416, 71° 22′ S, 18° 15′ W, in 2370 fathoms.

So far as can be seen all are of essentially the same form, though there is some not inconsiderable variation amongst them, which may be in part due to the different amounts of rolling. No. I has the earlier part of the test missing. No. VII appears to have been partially crushed during fossilization. Nos. I, II, III, VI and VII seem to be rolled and worn.

Description

The test consists of a simple, rather stout, rectilinear series of from 6 to 11 short chambers. In cross section it is more or less circular, though the smallest specimen, No. V particularly, shows appreciable flattening that appears to be original and not accidental. The chambers increase rapidly in diameter from the rounded proloculus, but the final one or two are sometimes of lesser diameter than the preceding chamber, i.e. in Nos. II, VI and VII.

The wall of the test is smoothly finished, though it is composed of small, angular quartz grains set in little cement. This was most clearly shown in one specimen, No. VIII, that was accidentally crushed. The wall does not react visibly with dilute hydrochloric acid, so that the cement is presumably not calcareous.

The two best preserved specimens, Nos. IV and V, show the sutures depressed, and the chambers somewhat inflated between them, particularly in No. V. The chambers are completely covered with an ornament of vertical striations. The initial and final chambers of even these two, however, appear to be broken.

No definite aperture is visible on any shell. Mounted in a transparent medium, no internal structure can be made out, though the tests are fairly transparent.

The specimens vary from 0·25 to 0·45 mm. in length and from 0·11 to 0·19 mm. in greatest breadth.

Affinities

The form appears most to resemble the genus *Monogenerina*, Spandel (1901). Unfortunately this genus is not adequately known, particularly as regards the material of which the test is composed. *M. texana*, Cushman and Waters (1928, Journ. Palaeont., ii, p. 363, pl. xlviii, figs. 1, 2), may be compared, though it has no ornamentation of striae, is much more compressed, and the wall is said to be perforate.

Other genera that may also be compared are *Nodosinella*, Brady, and *Cribrogenerina*, Schubert. As regards the external form it may be compared with such fossils as *Nodosaria irwinensis*, Howchin (1895, Trans. Roy. Soc. S. Australia, xix, p. 196, pl. x, figs. 7, 8), *Nodosaria striato-clavata*, Spandel (1898), Verlag des Verlags-Instituts "General-Anzeiger", Nürnberg, p. 9, text-fig. 6), which has been referred to the subgenus *Spandelinoides* by Cushman and Waters, 1928; and *Spandelina* (*Spandelinoides*) *striatella*, Cushman and Waters (*loc. cit.*, p. 368, pl. xlviii, figs. 12*a*, *b*). These three forms, however, appear to possess calcareous tests.

Rhapidionina, Stache, is another genus externally similar, but this is a calcareous form with a characteristic internal structure; I am practically familiar with this genus, from the Lower Eocene of British Somaliland, and it is clearly distinct.

Owing to the lack of essential literature in Baghdad, and my practical unfamiliarity with several of the above genera, of which examples are not at the moment available for direct comparison, it is difficult to carry the investigation farther at present.

Conclusion

One tentative remark may perhaps be hazarded. The form dredged from the Weddell Sea appears to belong amongst a group of genera, some of which are imperfectly known, which are characteristic of rocks of a late Palaeozoic age, Carboniferous and Permian. If the above view be correct, it would point to the interesting conclusion that strata of similar age must outcrop near by. The outcrop may be on the sea floor, but as the two stations are at no great distance from the Antarctic coast-line it is more likely that they have been carried to their position by ice action.

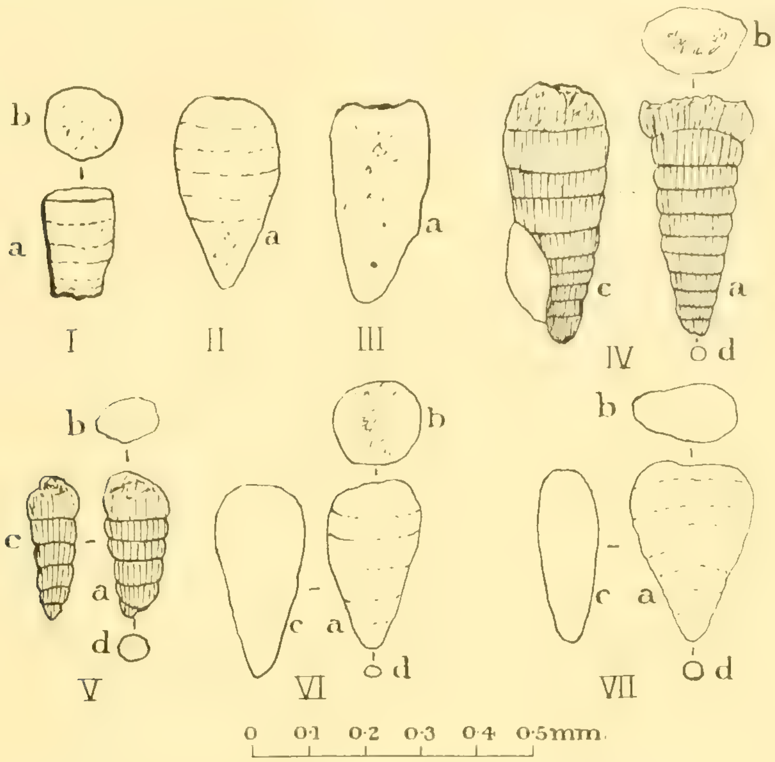

Fig. 1. Figures of ? *Monogenerina* sp. from the Weddell Sea, drawn from the individual specimens.
a, side view. *c*, edge view.
b, oral-end view. *d*, aboral-end view.

At St. 312, in 1956 fathoms to the south-east of the South Orkneys, a few pyritized diatoms and Radiolaria were observed. They resemble those to be found in the London Clay and other Tertiary deposits, but in view of the great distance of this station from the Antarctic coast-line, I hesitate to accept them as fossils. Recent Radiolaria are frequent and diatoms rare at this station, so the specimens may be of recent origin, altered by some chemical reaction.

MINERALS

Some interesting crystalline components observed in the deposits have been dealt with by Mr F. A. Bannister and Mr M. H. Hey in a Report appended, see pp. 60 *et seq.*

The "envelope" crystals, as will be seen, are composed of hydrated calcium oxalate and were observed at several stations besides St. 286, where they were first noticed.

I have not preserved a note of their frequency at that station, but believe they were fairly common. At St. 226 they are abundant and variable in size up to 0·3 mm. (300μ) in length of edge; some twinned and multiform specimens were also noted. At St. 290 they are abundant but small—average length of edge probably less than 0·1 mm. (100μ). At Sts. 295, 300, 303 and 387 they were very rare, and of small or average size. All the stations are in the very deep water of the Central Weddell Sea, and in both Blue Mud and Blue Mud approximating to Red Clay areas. None were seen at the inshore stations. It is, however, quite possible that the crystals occur elsewhere, for owing to their size, shape and generally glassy transparency, they would be easily overlooked among other mineral grains.

From the fact that the edges are invariably sharp and unbroken I have no doubt that this mineral, hitherto unknown in deep sea-deposits, is formed *in situ*.

The crystals of calcium sulphate or gypsum are frequent in the residues at Sts. 387, 391 and 428, rare at Sts. 290 and 422. Sts. 387 and 391 are in Pirie's Blue Mud approximating to Red Clay area, the others in the Blue Mud area, but all are far from land and in great depths, 2500–2715 fathoms. The crystals are similar to those which I have found abundantly in Gault and other fossil clays, and I have never previously seen them in a recent deposit. It is stated by Murray and Hjort (M. and H., 1912, DO, p. 176):

> From what is known of the solubility of gypsum in brines, and allowing for the excess of SO_4, one would suppose that sea-water is very nearly saturated for this salt, and that addition of, for instance, a sulphate would precipitate it. But gypsum is unknown as a constituent of deep-sea deposits (unless of extraneous origin), so that its solubility-limit is evidently never exceeded under submarine conditions.

From the condition of the crystals, which show little signs of disintegration, the distance of these stations from the Antarctic coast-line, and the fact that I have not observed any gypsum at the many stations nearer that line, it is difficult to believe that the mineral has not been formed *in situ*. The formation of the crystals may perhaps be evidence that the deposits in the Central Weddell Sea are accumulating very slowly, in spite of the evidence to the contrary afforded by the absence of whale's ear-bones noted by Pirie (see *ante*, p. 7).

A third crystalline component in nodular form has been identified as calcium citrate; it is common at St. 417, but was not observed elsewhere.

CORRECTED CONCLUSIONS TO BE DRAWN FROM THE RECORDS

As a result of my examination of the Scotia material many of the conclusions drawn from Pearcey's report on the same material published in the previous report (A, pp. 10–12, 23–5) require drastic revision. It was assumed on the basis of his lists that the foraminiferal fauna of the Weddell Sea was relatively scanty and of a cosmopolitan deep-water character; that it was isolated and had little in common with the fauna found to the west of the line of the Scotia Arc; and that there was practically no evidence of Pacific influence in the sea.

It is now apparent that Pearcey's examination of the Scotia material must have been of a perfunctory nature. Adding to the 229 species and varieties listed in this report the fifty-two species and varieties recorded by Pearcey which I did not find (see p. 5), and allowing for the few cases in which our identifications may overlap as noted on p. 5, we get a total of about 280 species and varieties within the convergence in the Weddell Sea sector, as against 138 recorded by Pearcey. Quite a numerous and exhaustive faunal list in itself, but taking into consideration that the minimum depth of the samples was 1131 fathoms, fairly conclusive proof that if shallow-water collections were available for examination, the faunal list from the Weddell Sea sector would probably equal the 500 or more species and varieties recorded from the Falkland sector of the Antarctic.

The casual nature of Pearcey's work is best shown by the fact that this report includes over 100 species described before the publication of Pearcey's report, and thirty-nine which have been described by various authors since 1914, in addition to the four new species now erected. The thirty-nine species described since the publication of his report include seven new genera, *Recurvoides*, *Ammomarginulina*, *Placopsilinella*, *Spirolocammina*, *Miliammina*, *Spiroplectammina* and *Delosina*.

It is particularly difficult to understand how Pearcey can have overlooked some of the large forms such as *Jaculella obtusa*, *Hormosina carpenteri*, *H. ovicula*, *H. lapidigera*, *Haplophragmoides weddellensis*, *H. sphaeriloculus*, *Cyclammina orbicularis*, and *C. bradyi*.

Until shallow-water material from the sector becomes available it will be best to reserve judgment as to the affinities of the Weddell Sea fauna. The present extended list remains largely deep-water cosmopolitan, as might be expected from the great depth of the material. But a few of the new species from the Falkland sector of the Antarctic are found in the Weddell Sea, generally in small numbers, e.g. *Thurammina protea* (No. 36), *Hyperammina tubulosa* (No. 41), *Ammobaculites foliaceus* var. *recurva* (No. 80), *Placopsilinella aurantiaca* (No. 82), *Trochammina inconspicua* (No. 95), *Spirolocammina tenuis* (No. 103), *Spiroplectammina filiformis* (No. 105), *Textularia tenuissima* (No. 107), *Gaudryina deformis* (No. 112), *Delosina wiesneri* (No. 114), *Nodosaria raphanistrum* var. (No. 185). It is impossible at present to say whether these originated in the Falkland sector and have invaded the Weddell Sea, or whether they have a circumpolar distribution. As regards some of them I regard the latter explanation as probable.

The question of Pacific influence has been dealt with on p. 10. The present report shows that there is a certain amount of such influence, distinctly traceable in a limited area in the extreme south of the Weddell Sea, to which it appears to be almost confined, but very limited as compared with that observed in the Falkland Sector.

Any general conclusions on the conditions of life in the Weddell Sea can only be tentative in view of the limited amount of material available and the large area involved. But it would seem that while the continental shelf and the abyssal plain at its foot contain a varied and extensive fauna, and the rate of deposition of the bottom deposits is probably much the same as elsewhere—perhaps slower than usual owing to the removal of diatoms and much fine matter by a northerly bottom current, the central Weddell Sea is restricted in fauna, and deposits are accumulating but slowly. If we accept the

minerals found in this area (pp. 13–14 and *et seq.*) as formed *in situ*, it seems probable that the rate of deposition must be very slow indeed.

ACKNOWLEDGMENTS

I have to thank the Director (Mr T. Rowatt) and Dr A. C. Stephen of the Royal Scottish Museum, Edinburgh, for the opportunity of examining the Scotia material. All types, station slides and species preparations have been deposited in that museum, for preservation with the rest of the Bruce collections. I have also to thank Dr S. W. Kemp, F.R.S., the Director, and Mr G. E. R. Deacon, of the Discovery staff, for constant advice and assistance; Dr W. A. Macfadyen of Baghdad for his report on the fossil Foraminifera; Professor J. Pia of Vienna for identification of the fossil Alga; and Mr F. A. Bannister and Mr M. H. Hey, of the Mineral Department of the British Museum for reporting on the minerals. Lastly, but not least, I thank the Discovery Committee for undertaking the publication of this report.

LIST OF STATIONS

A list of the stations within the Antarctic convergence which were worked over is given below. The positions of the stations are shown in Fig. 2.

226. (Deposit No. 8.)

17. ii. 03. 64° 18′ S, 23° 9′ W. Sounding, 2739 fathoms.

Glacial Clay. (Blue Mud approximating to Red Clay.)[1]

About 300 cc. of tenacious blue-brown clay which was difficult to wash and was dried twice. Only 1 cc. residue left on 150-mesh silk sieve—sand grains of all sizes, and a few Radiolaria. Pumice and volcanic glass in the finer residues. Abundant crystals of hydrated calcium oxalate. Foraminifera very rare, but twelve species were identified, all arenaceous except *Globigerina pachyderma*.

280. (Deposit No. 11.)

2. iii. 03. 68° 40′ S, 30° 18′ W. Sounding, 2511 fathoms.

Glacial Clay. (Blue Mud.)

About 150 cc. of tenacious blue clay, leaving only 1 cc. residue on 200-mesh silk sieve after trouble in washing. Foraminifera very rare with the exception of *Haplophragmoides subglobosus*, and entirely arenaceous.

282. (Deposit No. 12.)

3. iii. 03. 68° 31′ S, 32° 8′ W. Sounding, 2452 fathoms.

Glacial Clay. (Blue Mud.)

About 300 cc. of highly tenacious and slippery blue clay left only about 0·5 cc. residue on 150-mesh silk sieve. A few coarse sand grains, some fine sand and mica. Foraminifera extremely rare, only seven species, all arenaceous.

286. (Deposit No. 13.)

5. iii. 03. 68° 11′ S, 34° 17′ W. Sounding, 2488 fathoms.

Glacial Clay. (Blue Mud.)

About 150 cc. of tenacious grey clay of a very refractory nature. It was dried and washed twice, and finally broken down with hot soda. Residue 1 cc., consisting of abundant sand grains of all sizes, abundant *Globigerina pachyderma* and many small *Lagenae* and other calcareous Foraminifera.

[1] The nature of the deposit is that stated in the Station Log; the words in brackets indicate the area in which the station is situated on Pirie's chart.

Arenaceous Foraminifera were comparatively rare. Evidence of Pacific water influence indicated by several species, *Lagena exsculpta*, *L. fimbriata* var. *occlusa*, *L. stelligera*, *L. sidebottomi*, *L. desmophora*. Numerous crystals of hydrated calcium oxalate were observed.

290. (Deposit No. 14.)

6. iii. 03. 67° 39′ S, 36° 10′ W. Sounding, 2500 fathoms.

Glacial Mud. (Blue Mud.)

About 400 cc. of tenacious blue clay which, after drying, broke down readily, leaving very little residue: a manganese-coated pebble, many large sand grains, fine angular sand, a few crystals of gypsum and abundant crystals of hydrated calcium oxalate, mostly small. Sixteen species of arenaceous Foraminifera, mostly represented by single specimens, the most interesting species being *Hippocrepina flexibilis*. Sponge spicules and Radiolaria very rare; no diatoms.

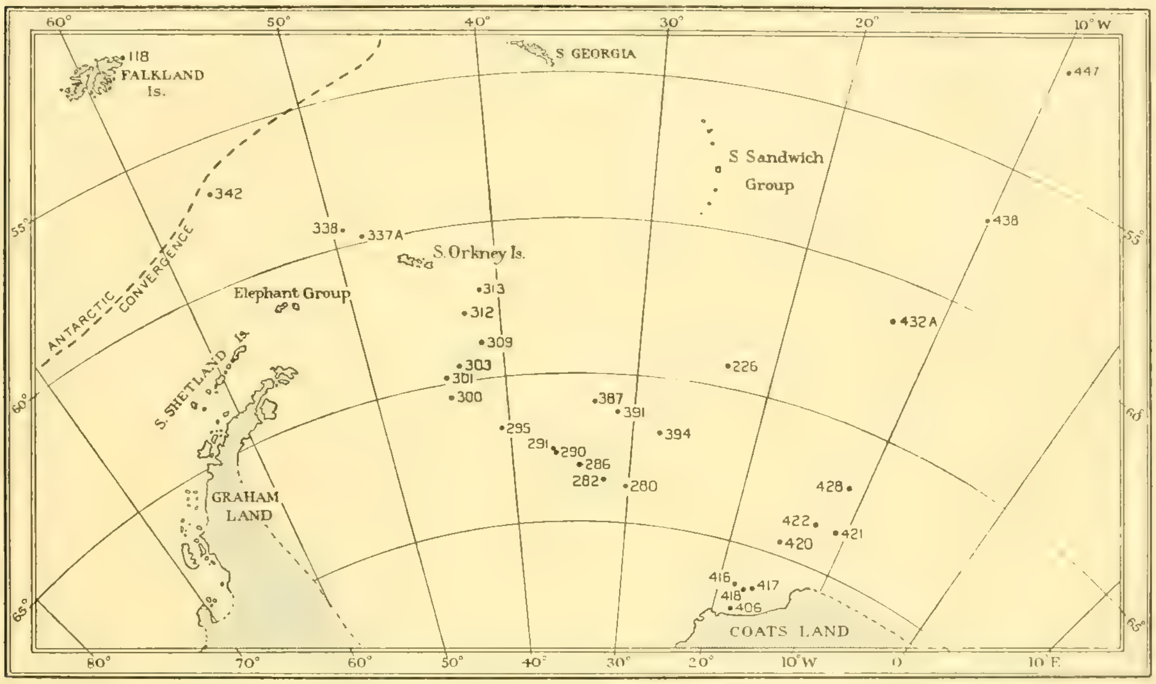

Fig. 2. Positions of stations from which Foraminifera were examined.

295. (Deposit No. 15.)

10. iii. 03. 66° 40′ S, 40° 35′ W. Sounding, 2425 fathoms.

Glacial Mud. (Blue Mud.)

About 180 cc. of tenacious slate-coloured clay was dried and washed twice, yielding as residue a pebble coated with manganese and sessile organisms, and about 1 cc. of angular sand grains of all sizes. Very few Radiolaria or sponge spicules, and no diatoms. Some glauconite, and a few small crystals of hydrated calcium oxalate. Foraminifera very rare; all arenaceous.

300. (Deposit No. 16.)

12. iii. 03. 65° 29′ S, 44° 6′ W. Sounding, 2500 fathoms.

Glacial Clay. (Blue Mud.)

About 150 cc. of tenacious blue clay which left hardly any residue on the 150-mesh silk sieve; angular sand grains of all sizes; Radiolaria and sponge spicules very rare; no diatoms; much mica and a few crystals of hydrated calcium oxalate; some unrecognizable fragments of large Foraminifera. The smaller species were scanty, worn and broken. *Cyclammina pusilla* was the only form occurring with any frequency; most of the others were represented by single specimens. Of the ten species listed, three were calcareous; viz. *Lagena globosa* var. *setosa*, *Globigerina pachyderma* and *Eponides bradyi*.

301. (Deposit No. 17.)

13. iii. 03. 64° 48′ S, 44° 26′ W. Sounding, 2485 fathoms.

Glacial Mud and Boulders. (Blue Mud.)

About 150 cc. of tenacious dark blue mud, drying grey, was washed twice and yielded very little residue of sand grains of all sizes up to $\frac{1}{8}$ in. No diatoms and hardly any Radiolaria or sponge spicules. A few Foraminifera in the coarser material, but practically none in the fine; entirely arenaceous except for a single specimen of *Globorotalia crassa*.

303. (Deposit No. 18.)

14. iii. 03. 64° 24′ S, 43° 18′ W. Sounding, 2547 fathoms.

Glacial Mud. (Blue Mud.)

About 300 cc. of tenacious grey mud leaving very little residue; sand grains of all sizes; many Radiolaria and a few sponge spicules, but no diatoms. Crystals of hydrated calcium oxalate very rare, only one or two seen. Foraminifera very rare but more varied than usual. The twenty-six species recorded include representatives of the three principal groups, and several interesting forms. Two species of *Miliolina*, *M. circularis* and *M. venusta*, represent the imperforate, and a single specimen of *Cassidulina laevigata* the hyaline Foraminifera; all the others have agglutinate tests.

309. (Deposit No. 19.)

16. iii. 03. 63° 51′ S, 41° 50′ W. Sounding, 2550 fathoms.

Glacial Clay. (Blue Mud.)

About 300 cc. of very tenacious blue grey clay left only 2 cc. residue on the 150-mesh silk sieve; two small pebbles without sessile organisms and fine sand; many Radiolaria and sponge spicules; about six diatoms seen. Foraminifera, except *Haplophragmoides subglobosus*, almost absent. Five arenaceous species in all were listed.

312. (Deposit No. 20.)

17. iii. 03. 62° 56′ S, 42° 20′ W. Sounding, 1956 fathoms.

Glacial Mud. (Blue Mud.)

About 300 cc. of tenacious blue clay drying in hard lumps which broke down readily, nearly all passing through the 150-mesh silk sieve. Residue a few large sand grains and fragmentary large Foraminifera; many Radiolaria and sponge spicules and fine sand, both quartz and flint. Occasional diatoms, but extremely uncommon. Foraminifera rare but varied, including *Spiroplectammina filiformis*, *Ammomarginulina ensis*, *Textularia tenuissima* and *Spirolocammina tenuis*. A few of the Radiolaria and diatoms were pyritized—possibly fossils.

313. (Deposit No. 21.)

18. iii. 03. 62° 10′ S, 41° 20′ W. Sounding and trawl, 1775 fathoms.

Glacial Mud or sand and boulders over 2 cwt. (Blue Mud.)

Three samples were received:

A. Sounding: about 350 cc. of hard lumps of dry blue mud which broke down readily. Residue pebbles and angular sand grains of all sizes; organisms of any kind except Radiolaria very rare; a few Foraminifera of many species; Radiolaria plentiful, sponge spicules not uncommon, and diatoms very rare.

B. A tube of sand—evidently washings from A.

C. About 300 cc. of coarse material labelled "Siftings from Trawl". Coarse sand with little mud. Arenaceous Foraminifera abundant, especially *Hormosina globulifera*, *Psammosphaera fusca*, *Haplophragmoides weddellensis*, *H. subglobosus* and *Reophax nodulosus*. Porcellanous and hyaline forms very scantily represented. No less than eight species of *Thurammina* were found at this station.

338. (Deposit No. 27.)

28. xi. 03. 59° 23′ S, 49° 8′ W. (In the Scotia Sea.) Sounding, 2180 fathoms.

Diatom Ooze and Volcanic Sand. (Diatom Ooze.)

A small tube of very refractory pale-grey mud. Residue aggregates of fine sand, Radiolaria and diatoms (*Coscinodiscus*) bound together with filamentous diatoms. Sponge spicules and Foraminifera almost entirely absent.

342. (Deposit No. 28.)

30. xi. 03. 56° 54′ S, 56° 24′ W. (In the Scotia Sea.) Sounding, 1946 fathoms.

Globigerina Ooze. (Globigerina Ooze.)

Only a few cc. of hard and refractory ooze. Residue of mud aggregates, *Globigerinae* and fine sand.

This station was not worked out, the amount of material being insufficient.

387. (Deposit No. 30.)

26. ii. 04. 65° 59′ S, 33° 6′ W. Sounding, 2625 fathoms.

Glacial Clay. (Blue Mud approximating to Red Clay.)

About 300 cc. of very tenacious blue-grey clay. Refractory—it was dried twice and finally broke down with hot soda. Only 1 cc. residue left on the 150-mesh silk sieve, consisting of angular sand grains of all sizes and many small crystals of gypsum. Foraminifera almost absent, only five arenaceous species being listed. Radiolaria and sponge spicules very rare. No diatoms seen. Crystals of hydrated calcium oxalate present in very small numbers. The finest residue consisted of refractory clay aggregates.

391. (Deposit No. 31.)

27. ii. 04. 66° 14′ S, 31° 18′ W. Sounding, 2630 fathoms.

Glacial Clay. (Blue Mud approximating to Red Clay.)

About 200 cc. of tenacious grey clay which left only 1 cc. residue on the 150-mesh silk sieve. Sand grains of all sizes, some Radiolaria, a few sponge spicules and fragments of three species of arenaceous Foraminifera. Crystals of gypsum frequent but small.

394. (Deposit No. 32.)

28. ii. 04. 66° 43′ S, 27° 55′ W. Sounding, 2685 fathoms.

Glacial Clay. (Blue Mud approximating to Red Clay.)

About 150 cc. of highly refractory slate-blue clay showing signs of lamination. After protracted treatment it was at last broken down and yielded about 3 cc. of residue, flakes of clay, a few sand grains and Radiolaria. No diatoms or sponge spicules. Foraminifera almost absent, four arenaceous species only listed.

406. (Deposit No. 33.)

3. iii. 04. 72° 18′ S, 17° 59′ W. Sounding, 1131 fathoms.

Glacial Mud. (Blue Mud.)

About 300 cc. of dark slate-coloured mud, granular and laminated, giving a residue of angular sand grains of all sizes, mostly very small but ranging up to $\frac{1}{4}$ in. in diameter. Many sponge spicules and large and small Radiolaria; a few small diatoms were found in the residue retained on the 200-mesh silk sieve. Foraminifera very rare, but over 20 species were listed, including some small specimens of *Miliammina arenacea*, the only record of the genus in the Weddell Sea.

A few minute fossils were obtained from this sounding which are more fully referred to on p. 11.

416. (Deposit No. 37.)

17. iii. 04. 71° 22′ S, 18° 15′ W. Sounding, 2370 fathoms.

Glacial Mud. (Blue Mud.)

About 300 cc. of dark slate-blue clay with sand left a residue of 35 cc. fine angular sand with much glauconite. Hardly any Radiolaria or sponge spicules, and no diatoms. The residue was floated with carbon-tetrachloride, but without results other than four specimens of *Haplophragmoides subglobosus*, three of *Cyclammina pusilla* and single specimens, more or less fragmentary, of three other species. A few minute fossils were found (see p. 11).

417. (Deposit No. 38.)

18. iii. 04. 71° 22′ S, 16° 34′ W. Sounding and trawl, 1410 fathoms.

Glacial Mud and Stones. (Blue Mud.) Bruce records that the trawl gave a rich haul with about 60 species.

Two samples were received:

A. Sounding: about 150 cc. of grey mud in hard dry lumps which were refractory and did not disintegrate readily. It was dried again and treated with soda. Residue *Globigerinae* and fine sand. Very few Radiolaria or sponge spicules and no diatoms. *Globigerina* spp. formed quite 98 per cent of organisms, the remainder furnished a long list of interesting species including many *Lagenae*, but the number of specimens was generally small. No *Globorotaliae* were observed.

B. A small jar of trawl debris, sponge fragments, coarse sand and abundant large arenaceous Foraminifera. This material was unfortunately in bad condition and was cleaned with difficulty. The spirit had evaporated and the whole was matted together with fungoid mycelium. Some nodular crystals of calcium citrate were common.

The foraminiferal fauna of this station shows considerable evidence of Pacific water influence.

418. (Deposit No. 39.)

19. iii. 04. 71° 32′ S, 17° 15′ W. Sounding, 1221 fathoms.

Glacial Mud and Rocks. (Blue Mud.)

About 200 cc. of tenacious blue clay, difficult to wash. Nearly all passed through the 150-mesh sieve. Residue a few large sand grains, mud aggregates and fine sand. Foraminifera, except *Globigerina* spp. very scanty, but varied in species. Very few sponge spicules or Radiolaria, and still fewer diatoms which were extremely rare.

421. (Deposit No. 41.)

22. iii. 04. 68° 32′ S, 10° 52′ W. Sounding, 2487 fathoms.

Glacial Clay. (Blue Mud.)

About 200 cc. of tenacious clay, which was washed twice, gave a residue including some sand grains and pebbles up to ½ in. diameter, coated with manganese, also angular sand grains of all sizes. No diatoms and very few Radiolaria or sponge spicules. Very few Foraminifera in coarser residue, but the finer sand when floated with carbon-tetrachloride gave abundant *Globigerina* spp. and a long list of other forms, many of great interest and some of distinctly Pacific origin.

422. (Deposit No. 42.)

23. iii. 04. 68° 32′ S, 12° 49′ W. Sounding, 2660 fathoms.[1]

Glacial Clay. (Blue Mud.)

About 300 cc. of tenacious clay yielded as coarse residue a few small manganese-coated pebbles with *Tolypammina vagans* sessile on them; the fine residue consisted of refractory clay aggregates, sand grains, numerous Radiolaria and a few small crystals of gypsum. No diatoms and very few sponge spicules. Foraminifera other than *Globigerina pachyderma* very rare.

428. (Deposit No. 43.)

27. iii. 04. 66° 57′ S, 11° 13′ W. Sounding, 2715 fathoms.

Glacial Clay. (Blue Mud.)

About 300 cc. of very tenacious and slippery clay, extremely refractory. Washed three times it gave very little residue on the 150-mesh silk sieve. A few large sand grains with sessile *Tolypammina vagans*; clay aggregates, many Radiolaria, frequent crystals of gypsum (small); very few sponge spicules and an occasional diatom. Foraminifera very rare and entirely arenaceous.

432a. (Deposit No. 44.)

30. iii. 04. 61° 21′ S, 13° 2′ W. Sounding, 2764 fathoms.

Glacial Clay. (Blue Mud approximating to Red Clay.)

About 150 cc. of blue clay, laminated and very refractory. It was washed three times and finally

[1] Note in log: "Ross Deep obliterated. Ross obtained 4000 fathoms, no bottom, in 68° 34′ S, 12° 49′ W."

with hot soda. Residue, clay aggregates of all sizes, some sand grains, a few Radiolaria and diatoms, practically no sponge spicules. Foraminifera, except *Glomospira charoides*, practically absent, five other species only recorded, fragmentary or single specimens.

438. (Deposit No. 45.)

3. iv. 04. 56° 58′ S, 10° 3′ W. Sounding, 2518 fathoms.

Diatom Ooze and Volcanic Sand. (Diatom Ooze.)

About 75 cc. of muddy lumps in fine mud which washed easily. Coarse residue, scoriae and pumice with a few large Foraminifera. Fine residue, Radiolaria, and fine volcanic sand with abundant diatoms but in less proportion than the sand. Foraminifera extremely rare; sixteen species in all, including *Spirolocammina tenuis*.

447. (Deposit No. 46.)

9. iv. 04. 51° 7′ S, 9° 31′ W. Sounding, 2103 fathoms.

Diatom Ooze and Rock. (Diatom Ooze.)

About 150 cc. of pale grey ooze, dry and in lumps; very hard to break down, the ooze being matted together with filamentous diatoms which felted in the sieves. Foraminifera varied; a long list, including several species of Pacific origin, but none present in any numbers except *Globigerina* spp.

LIST OF NEW SPECIES

Thurammina corrugata	*Trochammina soldanii*
Haplophragmoides weddellensis	*Eponides weddellensis*

SYSTEMATIC ACCOUNT

Note. To economize space no synonyms are given for species which have been described in the three previous reports. For purposes of reference the numbers given in the earlier reports, on the Falklands, South Georgia and Antarctic, are printed in brackets after the specific name, e.g. 2. *Pyrgo murrhyna* (Schwager) (F 3) (SG 1) (A 2). Those species recorded by Pearcey within the Antarctic convergence are noted, together with the numbers of the stations at which they were obtained.

Order FORAMINIFERA

Family MILIOLIDAE

Subfamily *MILIOLININAE*

Genus Pyrgo, Defrance, 1824

1. **Pyrgo depressa** (d'Orbigny) (F 2) (A 1).

One station: 417.

Only three specimens in all, one being very large.

Pearcey: 342, 420, 447 "sparingly at all".

2. **Pyrgo murrhyna** (Schwager) (F 3) (SG 1) (A 2).

One station: 417.

Two specimens only.

Pearcey: 342 "rare".

3. **Pyrgo vespertilio** (Schlumberger) (F 10A) (SG 4) (A 6).

One station: 417.

One large specimen only.

Pearcey (? as *Biloculina ringens* (Lamarck)): 420 "rare".

Genus **Miliolina**, Williamson, 1858

4. **Miliolina oblonga** (Montagu) (F 15) (SG 14) (A 14).

One station: 406.

A single small but typical specimen.

5. **Miliolina pygmaea** (Reuss) (F 25) (SG 18) (A 19).

Two stations: 406, 447.

Extremely rare and small.

6. **Miliolina venusta** (Karrer) (F 26) (SG 19) (A 20).

Three stations: 303, 417, 421.

Extremely rare and small, except at St. 417, where two medium-sized specimens were found.

Pearcey: 447 "few".

7. **Miliolina tricarinata** (d'Orbigny) (F 28) (SG 20) (A 22).

One station: 418.

One small but typical specimen.

8. **Miliolina circularis** (Bornemann) (F 29) (SG 21) (A 23).

Three stations: 303, 313, 417.

Very rare; a few large specimens at Sts. 313, 417; one small example at St. 303.

Pearcey: 420 "a few specimens". He notes that the calcareous shells show no sign of pauperation in spite of the great depth (2620 fathoms). My specimens agree with his in this respect.

9. **Miliolina labiosa** (d'Orbigny) (F 34) (A 26).

Two stations: 438, 447.

Extremely rare, small and thin-walled at both stations.

Genus **Sigmoilina**, Schlumberger, 1887

10. **Sigmoilina obesa**, Heron-Allen and Earland (F 38) (SG 22) (A 28) (Plate I, figs. 2–4).

Two stations: 313, 417.

Very rare, but typical and very large. This is an extension of 10° latitude to the south of previous records.

11. **Sigmoilina tenuis** (Czjzek) (F 40) (SG 23) (A 30).

One station: 417.

A single large and complanate specimen (see A 30).

Pearcey: as *Spiroloculina tenuis*, but only outside the convergence.

12. **Sigmoilina sigmoidea** (Brady) (A 31).

Two stations: 417, 421.

Rare; the specimens, though typical, are small at St. 417, and very small at St. 421.

Subfamily *KERAMOSPHAERINAE*

Genus **Keramosphaera**, Brady, 1882

13. **Keramosphaera murrayi**, Brady (Plate I, figs. 7–9).

Keramosphaera murrayi, Brady, 1882, K, pp. 242–5, pl. xiii, figs. 1–4; 1884, FC, pp. 224–7, text-figs. 8 *a–d* on p. 225.
K. murrayi, Pearcey, 1914, SNA, p. 996.
K. murrayi, Wiesner, 1931, FDSE, p. 111, pl. xvii, figs. 199–200.

Two stations: 313, 417.

A single perfect specimen, and a fragment showing the internal structure, were found at St. 313; also a single fairly good specimen at St. 417, which had evidently been built into the wall of a worm tube or other organism. They are all undersized and probably young individuals.

The perfect specimen from St. 313 is 1·5 mm. in diameter as compared with 2·5 mm., the size given by Brady for the type. The specimen from St. 417 is approximately the same size. Pearcey does not record the size of the Scotia specimen. Of Wiesner's two specimens, judging by the photographs, one is slightly larger than the type, the other rather smaller. They were obtained at Gauss St. 83, 3410 m., "sandy glacial mud" (65° 15′ S, 80° 19′ E).

Pearcey: "A perfect specimen among the material from St. 420, 2620 fathoms, in the Weddell Sea, outside the diatomaceous zone, in a terrigenous deposit of glacial mud containing but a trace of carbonate of lime." He also records the information that three additional specimens had been found in material from the original Challenger Station 157 (53° 55′ S, 108° 35′ E, 1950 fathoms), subsequent to the publication of the Challenger report, making in all five Challenger specimens. There should therefore now be in existence eleven specimens:

Five from the 'Challenger'.

One from the 'Scotia' (Pearcey), whereabouts unknown.

Three from the 'Scotia' (A.E.) in Royal Scottish Museum, Edinburgh.

Two from the 'Gauss', presumably in the Zoological Museum of the University of Berlin with the other Gauss specimens.

The known range of *Keramosphaera* now extends from 41° 20′ W (Scotia St. 313) to 108° 35′ E (Challenger St. 157) between latitudes 53° 55′ S (Challenger) and 71° 22′ S (Scotia St. 417), an enormous area at present little known. Though unquestionably a rare form, I think it is likely to be found whenever suitable material is obtained from

this area, although it does not figure in the list of species found by F. Chapman and W. J. Parr in the material collected by the Mawson Expedition between 60°–70° S and 90°–150° E, or from this Expedition's deep-water Stations between Australia and the Antarctic. It is possible that the species may be found in greater numbers in shallower water nearer the Antarctic coast-line, which would seem a more natural habitat for such a large porcellanous species. As no specimen has ever been found in the Pacific or western area of the Antarctic, the species is probably peculiar to the eastern area between Graham Land and the Kerguelen plateau.

Until more material is available the real structure of the organism must remain speculative, but after a careful examination of my specimens I am inclined to the belief that the structure is not so complex as Brady thought. He regarded the sphere of *Keramosphaera* as analogous to the disc of *Orbitolites* in structure, but to me the structure seems quite different. If a specimen of *Keramosphaera* is examined by direct light while immersed in fluid, it shows the chambers filled with air. They present the appearance of unseptate tubes wandering irregularly in all directions, dividing and joining again and passing over and under one another. There is no definite septation visible in the tubes but a slight constriction at intervals, and especially at the point of division. The tubes open on the surface in numerous low arched apertures (Plate I, fig. 9) with slightly thickened lip. These layers of tubules are concentric, for the test when it breaks shows a tendency to separate at the layers, as shown in Hollick's fig. 2 (B. 1882, K, pl. xiii, fig. 2), and in one of my specimens from St. 313. Examination of a fractured surface of the section photographed by Wiesner or even the section figured by Hollick (fig. 3, *ut supra*), seems to confirm this tubular structure rather than the layers of chamberlets postulated by Brady. If this suggested tubular structure is borne out by further research, the subfamily Keramosphaerinae would probably be found to be nearer akin to the Nubecularinae than to the Alveolininae.

Keramosphaera is not easily illustrated, and I think the admirable photographs of Wiesner are more truthful than the original drawings of Hollick. They bring out the characteristic blistered surface texture, and show the apertures.

Family ASTRORHIZIDAE

Subfamily *ASTRORHIZINAE*

Genus **Astrorhiza**, Sandahl, 1857

14. **Astrorhiza arenaria**, Norman.

Astrorhiza limicola, M. Sars, 1868 (*non A. limicola*, Sandahl), LUHD, p. 248; G. O. Sars, 1871, HF, p. 252.

A. arenaria, Norman, 1876, V, p. 213.

A. arenaria, Brady, 1879, etc., RRC, 1879, p. 43; 1882, FKE, p. 711; 1884, FC, p. 232, pl. xix, figs. 5–10.

A. arenaria, Pearcey, 1914, SNA, p. 997.

One station: 432A.

Only a fragment, probably referable to this species.

Pearcey: 291, 420 (apparently many, *A.E.*).

Genus Vanhoeffenella, Rhumbler, 1905

15. **Vanhoeffenella gaussi**, Rhumbler (SG 38) (A 51) (Plate I, fig. 5).

One station: 313.

A single specimen from 1775 fathoms, a notable extension of depth.

Genus Pelosina, Brady, 1879

16. **Pelosina cylindrica**, Brady (A 56) (Plate I, fig. 1).

One station: 417.

A single large specimen, 20 mm. in length, was found in the trawl washings from St. 417, on the continental slope off Coats Land. It has many specimens of *Hyperammina friabilis* and other species built into the wall of the test.

Pearcey: 313, 417, 420 "sparingly".

Genus Crithionina, Goës, 1894

17. **Crithionina granum**, Goës (F 54) (SG 46) (A 61).

One station: 290.

One small specimen.

18. **Crithionina mamilla**, Goës (F 55) (SG 47) (A 62).

One station: 313.

A single good specimen.

Subfamily *PILULININAE*

Genus Bathysiphon, M. Sars. 1872

19. **Bathysiphon filiformis**, G. O. Sars (A 70).

Eight stations: 226, 387, 394, 416, 421, 422, 438, 447.

Fragments only, sometimes not uncommon. The best and largest were found at Sts. 438, 447, 2518–2103 fathoms, diatom ooze. Judging by its absence from the trawl washings from Sts. 313, 417, the species does not favour a bottom of glacial clay or mud.

Pearcey: 301, 418, 420 "nowhere abundant". He refers to the fact that the outer layer of the test contains mineral particles of a larger size than is usually the case. This characteristic is seen in specimens from several of my stations, but not universally.

20. **Bathysiphon argillaceus**, Earland (A 75).

One station: 313.

Only a single specimen.

Subfamily *SACCAMMININAE*

Genus Sorosphaera, Brady, 1879

21. **Sorosphaera depressa**, Heron-Allen and Earland (SG 55) (A 77).

One station: 417.

A single-chambered detached specimen, probably referable to this species.

Genus **Psammosphaera**, F. E. Schulze, 1875

22. **Psammosphaera fusca**, Schulze (F 60) (SG 56) (A 79).

Nineteen stations: 226, 280, 282, 286, 290, 295, 301, 303, 309, 312, 313, 338, 416, 417, 418, 422, 428, 432 A, 447.

Universally distributed but uncommon at most stations. Frequent in the soundings from Sts. 290, 303 and 312 and abundant in the trawl washings from Sts. 313, 417. As usual the species exhibits great variation. The most generally distributed is the roughly constructed form figured in F (pl. viii, figs. 3, 4), which attains a large size in the trawl washings. The typical sphere of Schulze, in which the sand grains are of approximately equal size, is comparatively rare, but represented the species at Sts. 286, 338, and was observed in moderate numbers with the rough type at Sts. 313, 417, 422. Sessile and double specimens were frequent in the trawl washings, and were observed at several other stations.

Pearcey: 286, 313, 337 A, 342, 416, 417, 418, 420 "larger and more abundant on glacial deposits than in the *Globigerina* oozes"—I agree.

23. **Psammosphaera parva**, Flint (SG 57) (A 81).

Two stations: 406, 422.

A single specimen at each station.

Genus **Saccammina**, M. Sars, 1868

24. **Saccammina sphaerica**, M. Sars (SG 60) (A 83).

One station: 417.

Small roughly constructed specimens, without produced neck and having merely a simple aperture, are not uncommon in the trawl washings from St. 417. They are not easily distinguishable from *Psammosphaera fusca* except by their larger size. This may have caused them to be overlooked at other stations.

In a small tube of various specimens picked out from the trawl on the ship were a few gigantic individuals, mostly typical, of smooth construction and with produced neck. In the same tube were others of similar rough construction to those referred to above.

Pearcey: 291, 301, 313, 417, 420 "in considerable numbers, of large size and typical".

Genus **Proteonina**, Williamson, 1858

25. **Proteonina difflugiformis** (Brady) (F 61) (SG 62) (A 85).

Nine stations: 226, 286, 290, 295, 301, 303, 312, 417, 428.

Common at St. 303, rare or very rare elsewhere. Except at St. 312, where two large coarsely constructed specimens were found which might be primordials of *Reophax* sp., all the examples are of a small, neatly constructed, flask-shaped form.

Pearcey: 300, 337 A, 338, 342, 387, 447 "it was not found at any of the stations south of the circle".

26. **Proteonina tubulata** (Rhumbler) (SG 64) (A 86) (Plate I, fig. 6).

Two stations: 303, 422.

Three excellent specimens at St. 303, and one at St. 422.

Genus **Tholosina**, Rhumbler, 1895

27. **Tholosina bulla** (Brady) (F 65) (SG 67) (A 94).

Two stations: 313, 438.

One good specimen at St. 313; represented only by "scars" on sand grains at St. 438.
Pearcey: 420 "several specimens attached to *Rhabdammina*, etc."

28. **Tholosina vesicularis** (Brady) (F 67) (SG 69) (A 97).

One station: 313.

A single specimen.

Genus **Thurammina**, Brady, 1879

29. **Thurammina papillata**, Brady (SG 72) (A 99).

Three stations: 280, 313, 417.

Single specimens at Sts. 280, 417; many large individuals at St. 313, presenting great contrast in the relative proportions of sand and cement, some being quite smooth and formed almost entirely of cement, while others are roughly sandy.

Pearcey: 291, 420 "rarely".

30. **Thurammina corrugata**, sp.n. (Plate I, figs. 10, 11).

Two stations: 313, 417.

A young individual at St. 313; fragments of one or more large specimens at St. 417.

Test approximately spherical, darkly ferruginous in colour; wall composed of very minute sand grains and ferruginous cement, extremely thin and crinkled all over, the inner surface duplicating the exterior—what are raised ridges exteriorly are depressed troughs interiorly, and *vice versa*. Apertures minute but numerous, scarcely produced above the surface of the external corrugations, rarely distinguishable on the inner side. They are more conspicuous but fewer in the young shell. Test very fragile in the dry condition, but probably flexible in life.

T. corrugata is, I think, unique in its genus in its wall characters. It is so uniformly thin that the external corrugations are exactly duplicated internally. The cavity of *Thurammina* is normally smooth, except for slight pits corresponding to the external apertures, even in such strongly decorated species as *T. favosa*.

I was at first inclined to associate my specimens with *Thurammina favosa*, var. *reticulata*, Pearcey (SNA, p. 1003, pl. i, figs. 11, 12), found by him "in moderate numbers" at St. 420. Pearcey's description is vague, the first paragraph would describe any form of *T. papillata*. In the second paragraph he describes the *exterior* as "marked by an irregular network of raised ridges which easily distinguish this form from the type *T. favosa*, Flint; the ridges are robust and irregular, of a much lighter colour than that

of the wall generally". Except as regards colour this part of the description might be held to apply to my specimens. But Pearcey makes no reference to ridges on the internal surface in his description, while his rather poor drawings indicate a smooth interior.

The young individual from St. 313 is about 0·35 mm. in diameter. The larger fragments from St. 417 are estimated to have formed a sphere 1·0 mm. in diameter.

31. **Thurammina castanea**, Heron-Allen and Earland (F 61 A) (A 100).

One station: 313.

A large but broken specimen.

32. **Thurammina haeusleri**, Heron-Allen and Earland (SG 73) (A 101).

One station: 313.

Two specimens only, one being very large.

33. **Thurammina favosa**, Flint (Plate I, fig. 14).

Thurammina favosa, Flint, 1899, RFA, p. 278, pl. xxi, fig. 2.
T. papillata var. *favosa*, Heron-Allen and Earland, 1912, etc., NSG, 1917, p. 549, pl. xxviii, fig. 17.

Two stations: 313, 417.

A single large specimen at each station; that from St. 313 is attached to a large sand grain, but retains its spherical shape.

34. **Thurammina albicans**, Brady (SG 75) (A 102).

One station: 313.

Three good specimens were found.
Pearcey: 342 "two specimens".

35. **Thurammina cariosa**, Flint (A 105) (Plate I, figs. 12, 13).

One station: 313.

Four specimens, two being large and typical; the others double shells similar to those from the North Sea figured in H.-A. and E., 1912, etc., NSG, 1917, p. 550, pl. xxix, fig. 6.

36. **Thurammina protea**, Earland (SG 76) (A 108).

One station: 313.

One typical specimen sessile in a broken *Psammosphaera*.

Subfamily *RHABDAMMININAE*

Genus **Jaculella**, Brady, 1879

37. **Jaculella obtusa**, Brady (F 70) (SG 78) (A 111).

Two stations: 313, 417.

Good specimens are not uncommon in the trawl washings from these stations.

Genus Hippocrepina, Parker, 1870

38. **Hippocrepina flexibilis** (Wiesner) (SG 81) (A 113).

One station: 290.

Two good specimens.

Genus Hyperammina, Brady, 1878

Note. Fragments, not specifically identifiable, but probably referable to this genus, were observed at many stations, notably Sts. 295, 391, 406, 417. They have been disregarded.

39. **Hyperammina friabilis**, Brady (F 71) (A 115A).

Two stations: 313, 417.

Rare, but good specimens in the trawl washings.

Pearcey: 420 "a few typical specimens in a more or less fragmentary condition, but with the proloculum perfect".

40. **Hyperammina elongata**, Brady (F 72) (SG 85) (A 116).

Two stations: 313, 417.

Rare, but good specimens in the trawl washings.

Pearcey: 291 "few", 313 "rare", "walls built of coarser material than is seen in typical specimens". My specimens agree.

40A. **Hyperammina laevigata**, J. Wright (F 73) (SG 86) (A 117).

One station: 313.

One good specimen and a fragment.

41. **Hyperammina tubulosa**, Earland (A 120).

One station: 295.

Two fragments which appear to be referable to this species.

Genus Saccorhiza, Eimer and Fickert, 1899

42. **Saccorhiza ramosa** (Brady) (F 56A) (SG 89) (A 122).

Four stations: 303, 312, 313, 417.

Fragments are common at these four stations, largely built of spicules at St. 312, of sand with occasional spicules elsewhere.

Pearcey: 291, 313, 337A, 342, 417, 420 "nowhere numerous".

Genus Marsipella, Norman, 1878

43. **Marsipella cylindrica**, Brady (F 78) (SG 92) (A 125).

Two stations: 313, 447.

Fragments built of spicules are not uncommon at St. 313; rare, and built of sand, at St. 447.

Pearcey: 342 (frequency not stated).

Genus Rhabdammina, M. Sars, 1869

44. **Rhabdammina abyssorum**, M. Sars (F 79) (A 126).

Three stations: 313, 417, 418.

One small three-rayed specimen at St. 313; fragments, probably referable to this species, occurred rarely at the other stations.

Pearcey: 313, 337A, 417 "three-rayed form...more abundant at 337A than at the other two".

45. **Rhabdammina discreta**, Brady (F 80) (SG 93) (A 127).

Two stations: 313, 438.

A few poor specimens at St. 313; only one at St. 438.

Pearcey: 420 "fine well-developed specimens...in plenty".

46. **Rhabdammina linearis**, Brady (A 128).

Two stations: 313, 417.

Many good specimens at each station.

Genus Aschemonella, Brady, 1879

47. **Aschemonella catenata** (Norman).

Astrorhiza catenata, Norman, 1876, V, p. 213.
A. catenata, Brady, 1879, etc., RRC, 1879, p. 42, pl. iv, figs. 12, 13.
Aschemonella scabra, Brady, 1879, etc., RRC, 1879, p. 44, pl. iii, figs. 6, 7.
A. catenata, Brady, 1884, FC, p. 271, pl. xxvii, figs. 1–11; pl. xxviiA, figs. 1–3.
A. catenata, Pearcey, 1914, SNA, p. 1005.

Two stations: 312, 417.

Many fragments: large at St. 417, off Coats Land, smaller at St. 312 in the western Weddell Sea.

Pearcey: 420 "a few specimens".

Family LITUOLIDAE

Subfamily *LITUOLINAE*

Genus Reophax, Montfort, 1808

48. **Reophax scorpiurus**, Montfort (F 82) (SG 95) (A 133).

Four stations: 312, 313, 338, 428.

Frequent but small at Sts. 312, 338; rare elsewhere.

Pearcey: 342 "sparingly".

49. **Reophax curtus**, Cushman (A 134).

Two stations: 290, 313.

Rare at St. 313; one specimen at St. 290.

50. **Reophax pilulifer**, Brady (F 82A) (SG 97) (A 137).

One station: 417.

Only a single small specimen. The rarity of this species compared with its frequency in Discovery material (A 137) is no doubt due to the greater depth of the Scotia soundings.

Pearcey: 291, 301, 313, 420 "not common".

51. **Reophax fusiformis** (Williamson) (F 83) (SG 99) (A 138).

One station: 290.

A single small specimen.

52. **Reophax dentaliniformis**, Brady (F 84) (SG 101) (A 140).

One station: 313.

Very small and rare. The greater depth is probably responsible for the scarcity of a species so abundant in Discovery material (A 140).

Pearcey: 313, 447 "rare but typical".

53. **Reophax spiculifer**, Brady (SG 100) (A 141).

Three stations: 312, 406, 418.

Occasional fragments at each station.

54. **Reophax longiscatiformis**, Chapman (A 142).

Two stations: 313, 417.

Several fragments at St. 313; one only at St. 417.

55. **Reophax micaceus**, Earland (A 143).

One station: 303.

A single typical specimen.

56. **Reophax nodulosus**, Brady (F 84A) (SG 103) (A 145).

Eighteen stations: 226, 282, 286, 290, 295, 300, 301, 303, 313, 387, 391, 406, 417, 418, 421, 422, 428, 438.

One of the most typical species of the Weddell Sea deposits, found in more or less abundance in nearly all the soundings, generally in a fragmentary condition. Most of the fragments were of small specimens, probably not exceeding 3–4 mm. in length. In the trawl washings from St. 313 perfect specimens up to 5 mm. in length were frequent, they were regular and neatly constructed. At St. 417 the species reaches a gigantic size, the largest fragment was 16 mm. in length, and if perfect the specimen would have exceeded 25 mm. These large individuals are probably very old, they are coarsely constructed of large sand grains, and the chambers are elongate with constricted sutures.

Pearcey: 301, 313, 416, 417, 418, 420, 447. He notes the abundance and large size of the specimens at St. 417 "several measuring more than one inch in length".

57. **Reophax distans**, Brady (SG 104) (A 148).

Three stations: 312, 313, 438.

Large, very coarsely constructed fragments are not uncommon in the trawl washings from St. 313. Single neatly built fragments elsewhere.

Genus **Nodellum**, Rhumbler, 1913

58. **Nodellum membranaceum** (Brady) (A 153).

Two stations: 438, 447.

Extremely rare: a good specimen at St. 447.

Pearcey: 313 "rare".

Genus **Hormosina**, Brady, 1879

59. **Hormosina globulifera**, Brady (F 89) (SG 108) (A 154).

Nine stations: 290, 301, 303, 312, 313, 417, 428, 432A, 447.

Common at St. 313, and frequent at St. 417 in the trawl washings; also frequent in the soundings from Sts. 303 and 447; rare or very rare elsewhere. The majority of the specimens everywhere are megalospheric, rarely exceeding two chambers, but microspheric specimens up to 4–5 chambers were found at Sts. 303, 313, 417, exceptionally large at the last station. The tests are usually constructed of coarse sand and roughly finished, but of fine sand and cement, neatly finished at Sts. 428, 447.

Pearcey: 295, 420 "rare".

60. **Hormosina normani**, Brady (Plate I, fig. 19).

Hormosina normani, Brady, 1879, etc., RRC, 1881, p. 52; 1884, FC, p. 329, pl. xxxix, figs. 19–23.
H. normani, Pearcey, 1914, SNA, p. 1007.
H. normani, Wiesner, 1931, FDSE, p. 92, pl. x, figs. 119–21.

One station: 417.

Rare, but attaining a gigantic size and up to four chambers. These rapidly increase in diameter, and are neatly constructed, the walls being very thin. The largest specimen, fragmentary, had a final chamber nearly 5 mm. in diameter. It is probable that the species is widely distributed in the Weddell Sea, as fragments believed to be the apertural disc between successive chambers were seen in several soundings, the thin globular tests having become disintegrated.

Pearcey: 291 "not uncommon", 313 "rare", 417 "in fair abundance and of very large size".

61. **Hormosina carpenteri**, Brady.

Moniliform *Lituola*, Carpenter, 1875, M, 5th ed., p. 531, fig. *f*; 1881, 6th ed., p. 563, fig. *f*.
Hormosina carpenteri, Brady, 1879, etc., RRC, 1881, p. 51; 1884, FC, p. 327, pl. xxxix, figs. 14–18.

Four stations: 313, 417, 418, 421.

Fragments only, never exceeding two chambers, usually constructed of coarse sand, but at St. 313 of fine sand and cement as in the North Atlantic type.

62. **Hormosina ovicula**, Brady (A 155).

Two stations: 313, 447.

Rare fragments at each station. None of the specimens can have attained the size of those recorded from shallower water in the Palmer Archipelago (A 155).

63. **Hormosina ovicula** var. **gracilis**, Earland (SG 105) (A 156).

One station: 447.

Many single chambers of this fragile organism were found.

64. **Hormosina lapidigera**, Rhumbler (A 157).

Two stations: 313, 417.

Occasional specimens were found in the trawl washings.

Genus **Haplophragmoides**, Cushman, 1910

65. **Haplophragmoides canariensis** (d'Orbigny) (F 90) (SG 109) (A 158).

One station: 417.

A few rather small specimens at St. 417, off Coats Land.

Pearcey: 337A "rare".

66. **Haplophragmoides weddellensis**, sp.n. (Plate I, figs. 15–16).

Thirteen stations: 226, 282, 290, 295, 301, 303, 309, 313, 387, 394, 417, 418, 422.

Test massive and rough, nautiloid but not quite symmetrical, consisting of two or more convolutions with 5–6 chambers in the last convolution. Umbilical regions more or less depressed, one more so than the other. Constructed of sand grains, very large in proportion to the size of the test, firmly imbedded in ferruginous cement and projecting so as to give a very rough exterior. Aperture small and loop-like on the inner face of the final chamber.

Greatest breadth up to 2·0 mm. Thickness at final chamber about 1·2 mm.

Common in the trawl washings from Sts. 313 and 417: more or less rare at the remaining stations. It would appear that the size of the sand grains employed increases with advancing age; small and young individuals are less roughly constructed and use a larger proportion of cement. In large specimens the sand grains often project like rocks from the surface.

Most of the specimens which I succeeded in laying open had a large primordial chamber, but the microspheric form occurs at St. 309 and occasionally elsewhere. It is more neatly constructed and the sunken umbilici expose several convolutions of small chambers.

H. weddellensis belongs to the group of *H. canariensis* and is most nearly allied to *H. crassimargo* (Norman). But it differs, not only from that species but from all others of the genus, in its extremely coarse and irregular construction.

I cannot think how Pearcey can have failed to notice this form which is so abundant in the trawl washings. He describes and figures a new species *H. umbilicatum*, which

bears a general resemblance to *H. weddellensis* but differs in the number of chambers to the convolution, and is not so coarsely constructed, so far as can be judged by his figure. *H. umbilicatum* is reported as occurring "in abundance" at St. 420, but nowhere else. In the absence of his types, and of material from St. 420, I have not associated his species with the widely distributed form, but further research may prove the identity of the two species and reduce *H. weddellensis* to a synonym of *H. umbilicatus*. Alternatively Pearcey's species may prove to be the microspheric form of *H. weddellensis* (his figure suggests microspheric growth), which would also give his name priority.

67. **Haplophragmoides sphaeriloculus**, Cushman (F 93) (SG 111) (A 161) (Plate I, figs. 17, 18).

Eight stations: 303, 312, 313, 406, 417, 422, 428, 438.

Large specimens are not uncommon at St. 417, and single large specimens were also found at Sts. 312 (the only example), and 313 (species rare). Elsewhere all specimens were small; frequent at Sts. 303 and 428; rare or very rare at the other stations.

68. **Haplophragmoides trullissatus** (Brady) (A 162).

Six stations: 226, 282, 290, 300, 301, 313.

Rare at Sts. 301, 313, where both megalospheric and microspheric individuals were found. Very rare elsewhere.

Pearcey: 300, 337A, 416, 420 "rare". (See also No. 102.)

69. **Haplophragmoides scitulus** (Brady) (F 94) (SG 112) (A 163).

Four stations: 282, 416, 417, 422.

A single specimen at each station; that at St. 422 was built into the wall of *Psammosphaera*.

Pearcey: 291, 313, 416, 417 "rare". His records probably included the form since separated as *Recurvoides contortus* (No. 74).

70. **Haplophragmoides nitidus** (Goës) (A 165).

Two stations: 313, 417.

Two specimens at St. 313; frequent and typical at St. 417.

71. **Haplophragmoides subglobosus** (G. O. Sars) (F 95) (SG 113) (A 166).

Twenty-four stations: 226, 280, 282, 286, 290, 295, 300, 301, 303, 309, 312, 313, 387, 391, 394, 406, 416, 417, 418, 421, 422, 428, 432A, 447.

Recorded from every station within the convergence which was examined except Sts. 338 and 438, this is by far the most common and widely distributed species in the Weddell Sea, and is more or less common everywhere.

Two distinct forms occur, nearly always together, though often in varying proportions. One is very roughly built of large sand grains which project from the test; the other is smoothly constructed of smaller grains with more cement, and the exterior is neatly finished. The coarse form is generally larger than the smooth. At Sts. 406 and 418 only the smooth form occurs, and reaches the same size as the coarse form at other stations.

At Sts. 312, 313 and 417 the smooth form attains a large size, and the normal aperture is subdivided by bridges across the slit, as is often the case with large apertured species. It is the *Cribrostomoides bradyi* of Cushman, but I am convinced from a long study of the species in the *Haplophragmium* oozes of the Cold Area of the Faroe Channel that it is only an advanced stage of growth of *H. subglobosus*.

Pearcey's records are not easily understood. Of the type he says that it occurs at Sts. 300, 313, 416, 417, 418, 420, 447, "but nowhere common". He records *Cribrostomoides bradyi*, Cushman, separately as "rare" at Sts. 313, 418, 420.

72. **Haplophragmoides glomeratus** (Brady) (SG 114) (A 167).

Six stations: 226, 301, 303, 312, 313, 417.

Frequent at St. 417; rarer at Sts. 312, 313 where the specimens were large; very rare elsewhere.

Pearcey: 420 "rare".

73. **Haplophragmoides rotulatus** (Brady) (SG 115) (A 168).

Four stations: 312, 313, 406, 417.

Very rare, except at St. 406 where the specimens are rather more numerous, smaller and less coarsely constructed than at the other stations. None of them can be regarded as quite typical.

Pearcey: 337A "few", 342 "rare".

Genus **Recurvoides**, Earland, 1934

74. **Recurvoides contortus**, Earland (A 169) (Plate I, figs. 20–22).

Eight stations: 300, 301, 303, 313, 394, 406, 417, 421.

Rare everywhere except at Sts. 406, 417 where the species is not uncommon and a good series was obtained; less frequent at St. 313. These three stations are in shallower water (1131–1775 fathoms) than the others, which all lie near the 2500 fathom line.

Pearcey's records of *Haplophragmoides scitulus* (No. 69) probably included this species. He also records *Trochammina turbinata* (Brady) at Sts. 300, 447 "rare". This is hardly likely to have been Brady's species (see A, p. 91) but may have been *Recurvoides contortus*.

Genus **Ammobaculites**, Cushman, 1910

75. **Ammobaculites agglutinans** (d'Orbigny) (F 96) (SG 116) (A 170) (Plate I, figs. 23, 24).

Five stations: 303, 309, 313, 406, 417.

Large specimens are frequent in the trawl washings from Sts. 313, 417; single smaller individuals in the soundings from the other stations. As a rule specimens have only 2–3 chambers in the extended series, but typical many-chambered examples occur at St. 313.

Pearcey: 337A, 338, 342, 447 "nowhere very abundantly".

76. **Ammobaculites agglutinans var. filiformis**, Earland (SG 116) (A 171).

Four stations: 280, 286, 303, 417.

A single specimen at each station.

77. **Ammobaculites americanus**, Cushman (F 97) (SG 117) (A 172).

Two stations: 312, 313.

Very rare: two specimens at St. 312, and a single small individual at St. 313.

Pearcey: 342 "rare".

78. **Ammobaculites tenuimargo** (Brady) (SG 120) (A 173).

Two stations: 312, 313.

Only two specimens from the sounding at St. 312; common and large in the trawl washings from St. 313.

Pearcey: 313, 420 "rare".

79. **Ammobaculites foliaceus** (Brady) (SG 121) (A 174).

Three stations: 312, 313, 417.

Very rare everywhere, the best specimens at St. 312. Those from St. 417 were very small.

80. **Ammobaculites foliaceus var. recurva**, Earland (A 175).

Four stations: 303, 312, 313, 428.

Several typical specimens at St. 312; single typical individuals elsewhere.

Genus **Ammomarginulina**, Wiesner, 1931

81. **Ammomarginulina ensis**, Wiesner (SG 122) (A 176).

Three stations: 312, 313, 417.

Frequent and exhibiting great variation in the extent of the uncoiling of the chambers at St. 313; rarer at St. 312; a few small and pauperate specimens at St. 417, off Coats Land.

Genus **Placopsilinella**, Earland, 1934

82. **Placopsilinella aurantiaca**, Earland (A 178).

Two stations: 313, 417.

Not uncommon on sand grains at both stations, but easily overlooked. The chambers are smaller and darker than the type, resembling the North Atlantic specimens referred to in A 178.

Subfamily *TROCHAMMININAE*

Genus **Ammolagena**, Eimer and Fickert, 1899

83. **Ammolagena clavata** (Jones and Parker) (F 99) (SG 124) (A 179).

Three stations: 290, 313, 417.

A single small specimen from the sounding at St. 290; frequent in the trawl washings from Sts. 313 and 417.

Pearcey: 291 "common", 313, 342, 420 "rare".

Genus **Tolypammina**, Rhumbler, 1895

84. **Tolypammina vagans** (Brady) (F 100) (SG 125) (A 180).

Two stations: 422, 428.

A few specimens sessile on pebbles or large sand grains at each station.

Pearcey: 291, 417, 420 "fine typical specimens of a dark greyish-brown colour".

Genus **Ammodiscus**, Reuss, 1861

85. **Ammodiscus incertus** (d'Orbigny) (F 101) (SG 126) (A 181).

Three stations: 226, 301, 312.

Only a single very small specimen at each station. Its rarity is rather curious as the species is so universally distributed.

Pearcey: 337A "sparingly".

Genus **Glomospira**, Rzehak, 1885

86. **Glomospira gordialis** (Jones and Parker) (F 102) (SG 127) (A 183).

Five stations: 226, 290, 295, 303, 422.

Very rare everywhere. Free growing individuals at Sts. 303 and 422; both free and sessile at St. 295; sessile only at Sts. 226 and 290.

Pearcey: 342 "sparingly".

87. **Glomospira charoides** (Jones and Parker) (F 103) (SG 128) (A 184).

Twelve stations: 286, 290, 295, 300, 301, 303, 312, 313, 417, 428, 432A, 438.

Fairly frequent considering the poverty of the material at Sts. 312, 428 and 432A; at the last station ten small specimens were found, more than the number of specimens of all the other species present. Never more than two specimens at the remaining stations, all very small except two of normal size at St. 313. This is evidently one of the essential species of the glacial muds and clays.

Pearcey: 342, 416, 447 "not in any abundance".

Genus **Trochammina**, Parker and Jones, 1860

88. **Trochammina squamata**, Jones and Parker (F 104) (SG 131) (A 188).

Two stations: 295, 417.

A single specimen at St. 295; large, typical and frequent at St. 417, where one sessile individual was also found.

89. **Trochammina inflata** (Montagu) (F 108) (SG 134) (A 191).

Two stations: 303, 417.

A single specimen at each station.

90. **Trochammina malovensis**, Heron-Allen and Earland (F 109) (SG 135) (A 192).

Five stations: 286, 312, 313, 338, 406.

Extremely rare everywhere.

91. **Trochammina nana** (Brady) (F 110) (SG 136) (A 193).

Three stations: 312, 313, 417.

Frequent at St. 313; rare at St. 417; a single specimen at St. 312.

Pearcey: 337A "rare".

92. **Trochammina soldanii**, sp.n. (Plate I, figs. 32–34).

Three stations: 226, 290, 303.

Test free, rotaloid, inequilateral; spire depressed but visible on the dorsal side which is slightly umbilicate, the ventral side, exhibiting only the last convolution, being very deeply umbilicate. Consisting of about four convolutions, each of seven chambers. The two earlier convolutions are constructed of chitin and fine cement and the chambering is very distinct; the two later convolutions are increasingly coarse in structure and it is difficult to distinguish the chambers; the last convolution often contains large sand grains out of proportion to the rest of the test. Peripheral edge rounded; aperture very small on ventral side, near the junction of the final chamber with the preceding convolution.

Width up to 1·3 mm. Thickness at the final chamber 0·9 mm. Very rare, only an occasional specimen at each station. The species is very distinctive, isomorphous to some extent with *Rotalia soldanii*, d'Orbigny. Its nearest relative is probably *T. rossensis*, Warthin (W. 1934, FRS, p. 3, text-figs. 1–3), from the Bay of Whales, Ross Sea, 280 fms., from which it differs in its larger size, more deeply depressed ventral umbilicus and greater number of chambers.

93. **Trochammina bradyi**, Robertson (F 111) (SG 137) (A 196).

Three stations: 312, 417, 438.

A single large typical specimen at each station. Its rarity as compared with the Discovery records is remarkable. None of the malformed variety referred to in A 196 was observed.

94. **Trochammina globigeriniformis** (Parker and Jones) (F 110A) (SG 140) (A 197).

Five stations: 301, 313, 406, 417, 428.

Not uncommon at Sts. 313 and 417; very rare elsewhere. All the specimens are small.

Pearcey: 313, 337A, 342, 417, 447 "nowhere common".

95. **Trochammina inconspicua**, Earland (SG 139) (A 199).

Eight stations: 226, 300, 312, 313, 338, 406, 417, 428.

Not infrequent at Sts. 300 and 417; very rare elsewhere.

Pearcey's records of *T. globigeriniformis* may perhaps include specimens of this allied species.

Genus **Ammosphaeroidina**, Cushman, 1910

96. **Ammosphaeroidina sphaeroidiniformis** (Brady) (SG 142) (A 206).

Two stations: 313, 428.

A large specimen at St. 313, and two smaller at St. 428.

Genus **Cystammina**, Neumayr, 1889

97. **Cystammina pauciloculata** (Brady) (SG 144) (A 208).

One station: 447.

A single specimen.

Pearcey (as *Ammochilostoma* (*Trochammina*) *pauciloculata*): 447 "a few specimens".

Subfamily *LOFTUSINAE*

Genus **Cyclammina**, Brady, 1876

98. **Cyclammina cancellata**, Brady (F 114) (SG 147) (A 211).

Four stations: 280, 303, 418, 421.

Frequent at St. 421, both megalospheric and microspheric; single specimens only at the other stations. Nearly all are more or less abraded, and it is possible that the specimens may have been carried by ice from shallower water, as the species is not usually found in great depths. Some of the specimens at St. 421 are coated with a thin black layer of manganese, evidence that the shells have been dead for a long time.

Pearcey: 420, 447 "rarely".

99. **Cyclammina contorta**, Pearcey (Plate I, figs. 29–31).

Cyclammina contorta, Pearcey, 1914, SNA, p. 1009, pl. ii, figs. 5–7.

One station: 438.

Three specimens in more or less perfect condition, which I refer tentatively to Pearcey's species, though in the absence of his types identification is uncertain.

The specimens agree better with Pearcey's figure than with his description, in which he states that the last two convolutions completely envelop the others. The figures on the other hand show only one external convolution, and in this respect agree with my specimens.

I doubt whether *C. contorta* is anything more than a local form of *C. cancellata*. The colour scheme to which he draws attention is not a reliable diagnostic feature; the "suture lines, very dark, almost black" occur in one of my specimens, but not in the others, and may be due to a coating of manganese, as in some of my specimens of *C. cancellata* from St. 421.

Pearcey: 417, 420 "not abundant".

100. **Cyclammina orbicularis**, Brady (SG 148) (A 212) (Plate I, figs. 27, 28).

Five stations: 313, 406, 417, 418, 432A.

Common in the soundings from Sts. 406, 418 and in the trawl washings from St. 417, all of which are near the coast of Coats Land. Rare in the soundings from Sts. 313 and 432A which are far out in the Weddell Sea.

It is inexplicable how Pearcey can have overlooked this large species.

101. **Cyclammina pusilla**, Brady (A 213) (Plate I, figs. 25, 26).

Fourteen stations: 280, 282, 286, 290, 295, 300, 301, 303, 312, 313, 406, 416, 417, 418.

Common in the soundings at Sts. 282, 290, 295, 301, 312; frequent in soundings at

Sts. 280, 286, 300, 416, 418 and in the trawl washings at Sts. 313 and 417; rare elsewhere.

This is one of the most characteristic and widely distributed species of the Weddell Sea, and is more abundant in the deep water clays, where few species flourish, than near the Antarctic coast-line. Specimens vary greatly in size, the large microspheric form occurring with unusual frequency and sometimes predominating to the exclusion of the smaller megalospheric form. The number of chambers varies greatly between 10 and the typical 15 described by Brady.

Pearcey: 300, 313, 338, 416, 417, 420, 447 "but nowhere common".

102. **Cyclammina bradyi**, Cushman (A 214).

Nine stations: 290, 303, 309, 312, 313, 387, 417, 422, 428.

Occurs with variable frequency, but never common. The best and largest specimens in the trawl washings from Sts. 313 and 417; at the other stations specimens were rather under normal size. Both megalospheric and microspheric forms were noted at St. 309. As recorded in A 214, specimens often incorporate sand grains in the usual cement.

Pearcey does not record the species as such, but it is possibly included in his records of *Haplophragmoides trullissatus* (Brady) (No. 68), Cushman's species having been erected on one of Brady's figures of *Trochammina trullissata*.

Subfamily *SILICININAE*

Genus Spirolocammina, Earland, 1934

103. **Spirolocammina tenuis**, Earland (A 215) (Plate I, figs. 35–37).

Two stations: 312, 438.

Frequent at St. 312, to the south-east of the South Orkneys, and not very far from St. WS 199, the principal locality for the types; here 13 specimens were found, in all stages of growth. Only two specimens at St. 438, which is far to the north-east on the eastern edge of the Weddell Sea. Both stations are in very deep water, 1956–2518 fathoms, approximately the same depth as the original types from the Scotia and Bellingshausen Seas, 3264–4517 metres.

The sigmoiline curve is quite pronounced in young individuals, but becomes flattened out in large adult tests.

Genus Miliammina, Heron-Allen and Earland, 1930

104. **Miliammina arenacea** (Chapman) (SG, pp. 90, 92) (A 216) (Plate I, figs. 38–40).

One station: 406.

Twelve specimens in all were found at St. 406, the nearest inshore station off Coats Land, 1131 fathoms. They are all much below the average size, and only the largest have the specific characters sufficiently developed to be identified with certainty. The young individuals (as mentioned in A 216) are not specifically identifiable, but in the absence of adult specimens of the other species are almost certainly *M. arenacea*. All the specimens are nearly white in colour.

The discovery of *Miliammina* in the extreme south of the Weddell Sea is a noteworthy extension of the range of the genus, and my comments on the subject in the previous report (A, pp. 11, 24) require modification. The species may be found larger and better developed whenever material from shallower water in the Weddell Sea becomes available for examination. In any case the present discovery closes part of the long gap in the circumpolar records and, but for its absence from the records of the German South Polar expedition, the genus might be included among those having a circumpolar distribution. Such may eventually prove to be the case.

Family TEXTULARIIDAE

Subfamily *SPIROPLECTAMMININAE*

Genus **Spiroplectammina**, Cushman, 1927

105. **Spiroplectammina filiformis**, Earland (A 224).

Three stations: 280, 303, 312.

Single specimens at Sts. 280 and 303; four examples at St. 312. They are all typical as regards form, but not so deeply ferruginous as the type, the colour varying between light grey and brown. All the stations are in the central area of the Weddell Sea in very deep water, 1956–2547 fathoms.

Subfamily *TEXTULARIINAE*

Genus **Textularia**, Defrance, 1824

106. **Textularia catenata**, Cushman (A 228).

Four stations: 417, 421, 438, 447.

Very rare at St. 438; frequent to common at the other stations.

107. **Textularia tenuissima**, Earland (SG 156) (A 229)

Seven stations: 303, 312, 313, 338, 406, 417, 447.

Common at Sts. 312 and 313; frequent at St. 417; more or less rare elsewhere. The specimens are characteristic everywhere but vary greatly in size: small at St. 312, very large at St. 417, large at most other stations.

Pearcey's only records of *Textularia* within the convergence are *T. conica*, d'Orbigny and *T. concava* (Karrer) from St. 342 in the Scotia Sea. I have not seen either of these species. It is difficult to understand how he can have overlooked the genus in the Weddell Sea material. He records *Gaudryina pseudofiliformis*, Cushman, at Sts. 313 and 338, and in the previous report (A, p. 11) I suggested that this record might refer to *Gaudryina apicularis*, Cushman, which had been found in the deep water of the Scotia Sea. Having met with neither of these species of *Gaudryina* in the Weddell Sea, I am now inclined to the opinion that Pearcey's record may refer to *Textularia tenuissima*, which occurs at both stations mentioned by him.

108. **Textularia antarctica**, Wiesner (A 232).

One station: 417.

Only a few specimens at St. 417, off Coats Land, in 1410 fathoms. Its absence elsewhere is probably associated with the great depth of the deposits.

Subfamily *VERNEUILININAE*

Genus **Verneuilina**, d'Orbigny, 1840

109. **Verneuilina bradyi**, Cushman (SG 160) (A 234).

Three stations: 313, 406, 447.

Frequent at Sts. 406 and 447; a single large specimen at St. 313.

Pearcey: 342 "sparingly".

110. **Verneuilina bradyi var. nitens**, Wiesner (A 235).

Six stations: 286, 313, 417, 421, 422, 447.

Common at St. 421; rare or very rare elsewhere.

Genus **Gaudryina**, d'Orbigny, 1839

111. **Gaudryina bradyi**, Cushman (SG 161) (A 241).

One station: 406.

This species is represented by a single large specimen at St. 406, off Coats Land.

Pearcey: 342 in the Scotia Sea (56° 54′ S), which he claims as a southern record. St. 406 (72° 18′ S) considerably extends its range.

112. **Gaudryina deformis**, Earland (SG 163) (A 242).

One station: 417.

Not uncommon. Some of the specimens are even more irregular in growth than the types.

Genus **Clavulina**, d'Orbigny, 1826

113. **Clavulina communis**, d'Orbigny (SG 165) (A 247).

Eight stations: 312, 313, 338, 406, 417, 418, 438, 447.

Fairly frequent at all the stations, both megalospheric and microspheric forms being usually present. Except at St. 438, where the diatom ooze contains a large proportion of volcanic sand, and the few specimens are very dark, they have the characteristic Antarctic texture (see SG 165, A 247). At St. 447 a few of the specimens show a tendency to incorporate larger sand grains in the test.

Pearcey: 313 "rare", 337A "few", 342 "rare", 417, 418 "rare".

Family BULIMINIDAE

Subfamily *BULIMININAE*

Genus **Delosina**, Wiesner, 1931

114. **Delosina wiesneri**, Earland (A 266).

One station: 447.

A single good megalospheric specimen identical with the Discovery examples. The record is of great interest in linking up the known areas of distribution, which now extend from St. WS 482 in 57° 16′ 30″ W to the Gauss St. 56 in 89° 38′ E. It also marks a great extension of depth, Scotia St. 447 being in 2103 fathoms on diatom ooze, the previous maximum being 385 m. at the Gauss station.

Genus **Virgulina**, d'Orbigny, 1826

115. **Virgulina schreibersiana**, Czjzek (F 138) (SG 174) (A 269).

Six stations: 286, 312, 417, 418, 421, 447.

Frequent or common except at Sts. 312 and 447 where it is very rare. The specimens are usually large, especially at St. 417.

Pearcey: 417, 418 "nowhere abundant".

116. **Virgulina bradyi**, Cushman (F 141) (SG 176) (A 268).

One station: 447.

A single small specimen only from this station, just inside the convergence. Its rarity is remarkable.

Genus **Bolivina**, d'Orbigny, 1839

117. **Bolivina punctata**, d'Orbigny (F 143) (SG 177) (A 272).

One station: 418.

A single very small and pauperate specimen. The noticeable absence of this species in the Weddell Sea is probably accounted for by the great depth at most stations.

Subfamily *CASSIDULININAE*

Genus **Cassidulina**, d'Orbigny, 1826

118. **Cassidulina laevigata**, d'Orbigny (F 157) (SG 185) (A 283).

Three stations: 303, 417, 418.

Single specimens only at Sts. 303 and 417; rare at St. 418; they are all in deep water, 1131–2547 fathoms.

119. **Cassidulina crassa**, d'Orbigny (F 160) (SG 188) (A 286).

Four stations: 286, 417, 421, 447.

Never very common and all small at Sts. 286 and 421. Some very large specimens as well as small at Sts. 417 and 447.

120. **Cassidulina crassa** var. **porrecta**, Heron-Allen and Earland (F 161) (A 287).

One station: 447.

A single large specimen from 2103 fathoms, just inside the convergence.

121. **Cassidulina subglobosa**, Brady (F 162) (SG 189) (A 288).

Six stations: 286, 338, 417, 418, 421, 447.

Small specimens are frequent or common at Sts. 286, 418 and 421 and rare at Sts.

338 and 417. Very large, thick-walled specimens are frequent at St. 447, just inside the convergence.

Pearcey: 286, 313, 342, 417, 447 "not common at any of them".

122. **Cassidulina pacifica**, Cushman (A 291).

One station: 417.

Three large and well-developed specimens from St. 417, 1410 fathoms, off the coast of Coats Land.

This is a well-known Indo-Pacific species which was recorded (A 291) from the Drake Strait, where its presence was regarded as evidence of Pacific influence. Its occurrence so much farther south, and near the Antarctic coast-line, indicates that there is an inflow of Pacific water into this area of the Weddell Sea.

Not recorded by Pearcey inside the convergence, but "sparingly" at St. 346 on the Burdwood Bank.

Genus **Ehrenbergina**, Reuss, 1850

123. **Ehrenbergina bradyi**, Cushman (F 166) (SG 194) (A 294).

One station: 447.

Not uncommon, but small.

Pearcey's record of *E. serrata*, Reuss, at St. 342 probably refers to this species.

124. **Ehrenbergina hystrix**, Brady, var. **glabra**, Heron-Allen and Earland (F 165) (SG 192) (A 296).

Two stations: 417, 418.

Very rare at both stations, which are on the Continental slope off Coats Land. It may be more abundant in shallower water inshore.

Family LAGENIDAE

Subfamily *LAGENINAE*

Genus **Lagena**, Walker and Boys, 1784

Note. For greater convenience the species are arranged in alphabetical order.

125. **Lagena acuticosta**, Reuss (F 196) (SG 197) (A 302).

Three stations: 417, 421, 447.

Many good specimens at Sts. 417 and 421; two at St. 447.

Pearcey: 342 "rare".

126. **Lagena alveolata**, Brady (A 303).

Three stations: 417, 418, 447.

Frequent and typical at St. 417; rare at the other stations.

127. **Lagena alveolata** var. **separans**, Sidebottom (F 246) (A 305) (Plate I, figs. 41, 42).

One station: 421.

Five typical specimens at St. 421 in the south-east corner of the Weddell Sea; evidence of the penetration of Pacific water.

128. **Lagena alveolata var. substriata**, Brady (SG 198) (A 306) (Plate I, figs. 43, 44).

One station: 417.

Many excellent specimens of this Pacific form at St. 417.

129. **Lagena annectens**, Burrows and Holland (F 215) (SG 199).

Two stations: 417, 447.

One large, weak specimen at St. 417; several examples at St. 447.

130. **Lagena apiculata** (Reuss) (F 174) (SG 200) (A 308).

Three stations: 417, 421, 447.

The best and most typical specimens at St. 417, where it is rare. Frequent in elongate varieties at Sts. 421 and 447.

Pearcey: 342 "sparingly".

131. **Lagena aspera**, Reuss (F 182) (A 309).

One station: 421.

A single thin-walled specimen with the spines arranged in regular rows, not unlike Sidebottom's figure from the South West Pacific (S. 1912, etc., LSP, 1913, p. 167, pl. xv, fig. 11).

132. **Lagena biancae** (Seguenza) (F 210) (SG 202) (A 314).

Three stations: 417, 421, 447.

Frequent at St. 417; rare elsewhere; as usual showing great range of variation.

Pearcey recorded this species as *L. laevigata* (Reuss) (*non* d'Orbigny) only outside the convergence.

133. **Lagena catenulata**, Reuss (F 201) (SG 205) (A 318).

One station: 421.

A single weak specimen.

134. **Lagena clavata** (d'Orbigny) (F 178) (A 321).

One station: 286.

A single specimen.

135. **Lagena clavulus**, Heron-Allen and Earland (A 322) (Plate I, fig. 45).

One station: 421.

A specimen doubtfully referred to this species. It has a long neck and the projections are in some cases connected by what appear to be the remains of wings extending down the sides of the test. They may represent tubules passing through the wings of a test of the *lagenoides* group.

136. **Lagena costata** (Williamson) (F 195) (SG 207) (A 325).

One station: 421.

Two small but typical specimens.

137. **Lagena desmophora**, Rymer Jones (A 328) (Plate I, fig. 46).

One station: 286.

Two small specimens with exceptionally long necks and weak ornament resembling fig. 44 in A 328 were found at St. 286.

Pearcey records the species outside the convergence only.

138. **Lagena exsculpta**, Brady (A 330).

Three stations: 286, 421, 447.

Rare everywhere; typical but small at Sts. 286 and 421; larger but less typical at St. 447. Pearcey: 342, 447 "rare".

139. **Lagena felsinea**, Fornasini (SG 212) (A 332).

Four stations: 286, 417, 421, 447.

Very rare but typical.

140. **Lagena fimbriata**, Brady var. **occlusa**, Sidebottom (F 233) (A 334).

Two stations: 286, 417.

A single typical specimen at each station.

141. **Lagena formosa**, Schwager (SG 214) (A 335).

Two stations: 421, 447.

Two large and typical specimens at St. 421; a smaller example at St. 447.

Pearcey: 417 "very rare".

142. **Lagena foveolata**, Reuss (F 204) (SG 216) (A 337).

Two stations: 421, 447.

Very rare, but good slender specimens at St. 447.

143. **Lagena foveolata** var. **paradoxa**, Sidebottom (A 338).

One station: 421.

Many good specimens of this distinctly Pacific form.

144. **Lagena globosa** (Montagu) (F 169) (SG 217) (A 340).

Four stations: 286, 417, 421, 447.

Common at Sts. 417 and 421, and frequent at the other stations. All varieties are represented, including compressed and fissurine forms.

Pearcey: 417 "rare".

145. **Lagena globosa** var. **emaciata**, Reuss (A 341).

One station: 447.

A single specimen.

146. **Lagena globosa**, var. **setosa**, Earland (A 342).

Three stations: 300, 417, 421.

Three good specimens at St. 421; single examples elsewhere.

147. **Lagena gracilis**, Williamson (F 185) (SG 218) (A 344).

Two stations: 417, 421.

Good and typical specimens are frequent at St. 417; rarer at St. 421.

148. **Lagena gracillima** (Seguenza) (F 177) (SG 219) (A 345).

One station: 286.

A single specimen.

149. **Lagena hexagona** (Williamson) (F 202) (SG 222) (A 349).

One station: 421.

Very rare. The specimens have high walls surrounding the hexagonal pits.

150. **Lagena hispida**, Reuss (F 181) (A 350).

Two stations: 417, 418.

A single very weak specimen of normal type at each station.

151. **Lagena hispidula**, Cushman (F 180) (SG 223) (A 351).

Three stations: 417, 421, 447.

Frequent at Sts. 417 and 421; rarer at St. 447 where the few specimens were large and very typical.

152. **Lagena laevis** (Montagu) (F 179) (SG 224) (A 355) (Plate I, fig. 47).

Four stations: 286, 417, 418, 421.

Frequent and typical except at St. 418 where only two specimens were found, one being exceptionally large. At St. 286 a variety occurs, characterized by a long neck and globular body with base bearing a few short spines. It is similar to *L. globosa* var. *setosa* (No. 146), except for the long neck.

Pearcey: 118 "few".

153. **Lagena lagenoides** (Williamson) (F 226) (SG 225) (A 356).

Two stations: 417, 447.

Many good specimens of the broad-winged, many-tubuled, deep-water form figured in connection with F 226 were found at St. 417. At St. 447 a single small and pauperate specimen not unlike Sidebottom's figure (S. 1912, etc., LSP, 1912, p. 413, pl. xix, fig. 2).

154. **Lagena lagenoides var. tenuistriata**, Brady (F 228) (SG 226) (A 359).

One station: 417.

Many specimens at St. 417 representing two distinct forms; one is a striate variety of the deep-water form referred to in No. 153; the other is a smaller, more inflated variety with narrow wing. They represent Brady's figures 15 and 11 respectively (B. 1884, FC, pl. lx, figs. 11, 15).

155. **Lagena lamellata, Sidebottom (Plate I, figs. 48–50).**

Lagena lamellata, Sidebottom, 1912, etc., LSP, 1912, p. 396, pl. xvi, figs. 24, 25; 1913, p. 177.
One station: 417.

Six specimens from 1410 fathoms off Coats Land are, I think, referable to this obscure species. One specimen, practically undamaged, has a surface in agreement with Sidebottom's description, "built up of thin plates, arranged in an irregular manner, which, although rough, glisten to a certain extent". In the other specimens the outer covering is more or less completely abraded, leaving a finely spinous wall, as also described by Sidebottom. The unabraded wall has a very glittering appearance, as light is reflected at different angles by the minute plates on the surface.

The types were from 505–533 fathoms in the south-west Pacific about 16° S, 179° E, and apart from other specimens found in closely adjacent localities, I know of no further record of its occurrence. The presence of the species off the Antarctic coast-line seems to be definite proof of the penetration of Pacific water into the southern parts, at least, of the Weddell Sea.

156. **Lagena lineata (Williamson) (F 183) (SG 227) (A 361).**

One station: 417.

A single specimen, rather strongly striate and with a tendency to a spiral twist of the striae.

157. **Lagena longispina, Brady.**

Lagena longispina, Brady, 1879, etc., RRC, 1881, p. 61; 1884, FC, p. 454, pl. lvi, fig. 36 (only); pl. lix, figs. 13, 14.
L. longispina, Pearcey, SNA, p. 1016.
One station: 286.

Two large specimens, one broken, having the long solid spines typical of Brady's species.

Pearcey's only record is St. 459, outside the convergence. There is no evidence to show whether his specimens represented Brady's long-spined form, or the small form separated as *L. globosa* var. *setosa* (see No. 146 and A 342).

158. **Lagena marginata (Walker and Boys) (F 221) (SG 232) (A 364).**

Three stations: 417, 418, 421.

Frequent at St. 417 with moderately broad carina; very rare but with broad carina at St. 421; very rare and weak at St. 418.

Pearcey: 342 "sparingly".

159. **Lagena marginata var. cushmani, Wiesner (A 365).**

One station: 417.

Several very good specimens.

160. **Lagena marginata var. echinata (Seguenza) (Plate I, figs. 51–53).**

Fissurina echinata, Seguenza, 1862, FMMM, p. 58, pl. i, fig. 54.
One station: 421.

Six specimens found at St. 421 appear to be referable to Seguenza's species, which was described from a yellow Miocene marl from Sicily.

Seguenza describes his form as ovate, rough, rounded at the base, bluntly pointed at the oral extremity; surface roughly spinous, with a very obtusely rounded keel. His single figure illustrating the side view does not indicate much compression of the test; indeed he described the shell as only slightly compressed because the carina is very obtuse and rounded.

His specimens were presumably worn. The Scotia series shows every range between a specimen like Seguenza's figure, and one in which there is a distinctly produced neck from which a delicate carina extends down the edges for three-quarters of the length of the test. In a perfect specimen the carina would probably extend round the base also. The surface of the test is opaque, rough and finely hispid; the carina is glossy and smooth.

Length 0·2 mm. Breadth 0·14 mm. Thickness 0·08 mm.

The variety is clearly allied to *L. marginata*, and its chief interest lies in the fact that while the flask-shaped *Lagenae* exhibit a complete range of surface roughness between *L. aspera* and *L. hispida*, there is so far as I remember no other record of a compressed *Lagena* with a hispid surface.

The depth and distance from the Antarctic coast-line at St. 421 are, I think, sufficient to forbid any question of regarding the specimens as derived from a Miocene deposit ashore.

161. **Lagena marginata var. raricostata, Sidebottom.**

Lagena marginata, Walker and Boys, var.nov. *raricostata*, Sidebottom, 1912, etc., LSP, 1912, p. 408, pl. xviii, figs. 8, 9; 1913, p. 187.

One station: 447.

A single good specimen.

162. **Lagena marginata var. semimarginata, Reuss** (F 222) (A 369).

One station: 447.

A single specimen.

163. **Lagena marginata var. spinifera, Earland** (A 370).

Two stations: 421, 447.

Frequent at St. 421; rare but large at St. 447.

164. **Lagena orbignyana (Seguenza)** (F 240) (SG 236) (A 374) (Plate I, figs. 54, 55, 60, 61).

Three stations: 417, 418, 421.

Rare at St. 417, where two distinct forms occur. One is the typical North Atlantic variety with oval body and three feeble keels of approximately equal breadth figured by Brady (B. 1884, FC, pl. lix, fig. 25). The other has an almost circular body, and the median keel is very wide, especially round the base. It seems to resemble the variety separated by Cushman (C. 1910, etc., FNP, 1913, p. 45, pl. xxiii, fig. 1) as var. *alata*,

but in view of the fact that this name is preoccupied by Reuss (1851) for a different organism, and the enormous amount of variation in this species, I have not separated the forms.

All the specimens at St. 417 are large, as also was a single specimen of the broad-keeled form found at St. 418. Small specimens of the same form are frequent at St. 421.

Pearcey: 417, 447 "rare".

165. **Lagena orbignyana var. walleriana, J. Wright (Plate I, figs. 56–59).**

Lagena orbignyana var. *walleriana*, J. Wright, 1886, LB, p. 611; 1891, SWI, p. 481, pl. xx, figs. 8 *a*, *b*.

L. orbignyana var. *walleriana*, Sidebottom, 1912, etc., LSP, 1912, p. 417, pl. xix, fig. 21; 1913, p. 195.

One station: 417.

A small form, frequent at St. 417, resembles Wright's variety except in one important particular. The carinae are not continuous but in the basal area are traversed by bars, up to four in number, which separate the intercarinal spaces into rectangular pits. There are generally six of such pits occupying the basal margin of the shell, the central pits being larger in such cases, but sometimes there are only three cross-bars giving four pits. It was not seen at any other station, and I have not met with the form before.

This subvariety is very interesting, but the distinctive feature of Wright's variety, the central solid umbo of shell substance, is so strongly marked, that I have not thought it worth further distinction.

166. **Lagena palliolata, Earland (A 377).**

One station: 447.

A single specimen. The type was from deep water in the Drake Strait.

167. **Lagena quadrilatera, Earland (A 381).**

Two stations: 417, 421.

A single typical specimen at each station. The only previous records are in the Ross Sea and in Drake Strait, so this extension of range is of great interest.

168. **Lagena rizzae (Seguenza) (F 235).**

One station: 421.

A single specimen.

169. **Lagena schlichti (A. Silvestri) (F 225) (SG 241) (A 386).**

Three stations: 417, 418, 421.

Common at St. 417, some of the specimens being large; rare, or very rare, and smaller at the remaining stations.

170. **Lagena seguenziana, Fornasini (A 388).**

One station: 417.

A single typical specimen.

171. **Lagena semilineata**, J. Wright (A 389).

One station: 421.

Frequent specimens.

172. **Lagena sidebottomi**, Earland (A 393).

One station: 286.

Two good specimens. This is a most typical Pacific species, the outer range of which has hitherto been the recent record in Drake Strait (A 393). Its occurrence at a station in the middle of the Weddell Sea is therefore a noteworthy extension.

173. **Lagena squamosa** (Montagu) (F 197) (SG 243) (A 394).

One station: 417.

A single weak specimen.

Pearcey: 417 "not in any numbers".

174. **Lagena staphyllearia** (Schwager) (F 224) (SG 245) (A 397).

Five stations: 286, 417, 418, 421, 447.

Rare or very rare at all stations, but excellent specimens. The typical form with three basal spines represents the species at Sts. 417 and 418, and is larger than usual. The two-spined variety only is present at Sts. 286 and 447; both occur together at St. 421.

Pearcey: 447 "rare".

175. **Lagena stelligera**, Brady (A 398) (Plate I, fig. 62).

Three stations: 286, 421, 447.

Common at St. 421, not infrequent at the other stations. As usual there is considerable variation, but the majority of specimens at all stations are more or less devoid of basal costae, and both the neck and the basal tubule are longer than usual. Sidebottom's figure (S. 1912, etc., LSP, 1912, pl. xvi, fig. 2) represents the most frequent variation.

176. **Lagena stelligera** var. **eccentrica**, Sidebottom (A 399) (Plate I, figs. 63, 64).

Two stations: 417, 421.

Three large and typical specimens at St. 417. At St. 421 two specimens of a variation presenting a stout blunt spine in the centre of the basal ring.

177. **Lagena stewartii**, J. Wright (F 171) (SG 246) (A 401).

One station: 417.

A single good specimen.

178. **Lagena striata** (d'Orbigny) (F 188) (SG 247) (A 402).

Two stations: 313, 417.

Very rare: never more than two specimens at a station, and all of the long flask-shaped form figured by Williamson.

179. **Lagena sulcata** (Walker and Jacob) (F 189) (SG 248) (A 405).

Three stations: 417, 418, 421.

Frequent at St. 421, and very variable in the development and number of the costae. A single doubtful specimen at St. 418, and two of a curious compressed variety at St. 417.

180. **Lagena ventricosa**, A. Silvestri (SG 249) (A 409).

Four stations: 417, 418, 421, 447.

Common and large at St. 447; frequent good specimens at St. 417; rare or very rare at the other stations.

Subfamily *NODOSARIINAE*

Genus **Nodosaria**, Lamarck, 1812

181. **Nodosaria calomorpha**, Reuss (F 252) (SG 254) (A 413).

One station: 417.

A single specimen of two chambers only.

182. **Nodosaria communis**, d'Orbigny (F 254) (SG 256) (A 415).

Two stations: 286, 421.

Only single small specimens.

183. **Nodosaria mucronata**, Neugeboren (A 417).

One station: 447.

A single specimen.
Pearcey: 417 "rare".

184. **Nodosaria pauperata** (d'Orbigny) (F 255) (SG 257) (A 418).

Three stations: 417, 421, 447.

A few large specimens in fragments at St. 417; single examples at the other stations, large (microspheric) at St. 447.

185. **Nodosaria raphanistrum** (Linné) var. (A 421).

One station: 417.

A few specimens of the curious little variety figured in A 421 were found at St. 417, off Coats Land. Previously known from the Ross Sea and Drake Strait, its presence there, taken in conjunction with other species of like distribution (e.g. Nos. 122, 127, 128, 137, 143, 155, 167, etc.), seems evidence of the circulation of Pacific water into the most southern areas of the Weddell Sea.

Genus **Marginulina**, d'Orbigny, 1826

186. **Marginulina glabra**, d'Orbigny (SG 261).

Three stations: 417, 418, 447.

Three very good specimens at Sts. 417 and 418, and one very small example at St. 447.

Genus **Cristellaria**, Lamarck, 1812

187. **Cristellaria crepidula** (Fichtel and Moll) (F 268) (SG 262) (A 424).

One station: 417.

A single small specimen.

188. **Cristellaria acutauricularis** (Fichtel and Moll) (F 270) (A 425).

One station: 447.

A single small specimen from St. 447, diatom ooze, 2103 fathoms. The species is universally distributed, but always rare.

189. **Cristellaria obtusata**, Reuss (F 272) (A 427).

One station: 447.

Two small specimens.

190. **Cristellaria gibba**, d'Orbigny (F 274) (SG 263) (A 431).

One station: 417.

Two small specimens.

191. **Cristellaria cultrata** (Montfort) (F 278) (SG 264) (A 433).

One station: 417.

A single specimen.

192. **Cristellaria convergens**, Bornemann (F 281) (SG 265) (A 436).

Two stations: 421, 447.

Very rare but typical at both stations.

Pearcey: 337A "rare", 342 "few", 418 "rare", 447 "rare".

Subfamily *POLYMORPHININAE*

Genus **Glandulina**, d'Orbigny, 1826

193. **Glandulina laevigata**, d'Orbigny (F 248) (SG 252) (A 438).

One station: 417.

Only two broken specimens.

Genus **Polymorphina**, d'Orbigny, 1826

194. **Polymorphina cylindroides**, Roemer (A 443).

Two stations: 286, 313.

A single exceptionally large specimen at St. 313 and a very small example at St. 286.

195. **Polymorphina angusta**, Egger (A 445).

One station: 447.

Frequent small specimens.

Pearcey: 342, 447 "rare".

196. **Polymorphina problema**, d'Orbigny (F 289) (A 447).

One station: 418.

A single large specimen.

197. **Polymorphina extensa**, Cushman (A 448).

One station: 417.

One dead and worn specimen.

Genus **Uvigerina**, d'Orbigny, 1826

198. **Uvigerina angulosa**, Williamson (F 301) (SG 274) (A 454).

Two stations: 286, 418.

Two specimens at St. 418 and one at St. 286, all very small.

Family GLOBIGERINIDAE

Genus **Globigerina**, d'Orbigny, 1826

199. **Globigerina bulloides**, d'Orbigny (F 304) (SG 276) (A 456).

Four stations: 312, 417, 418, 447.

Frequent but small at St. 447, near the convergence; rare or very rare elsewhere except at Sts. 417 and 418, off Coats Land in 71° 22′ S to 71° 32′ S, where it is not uncommon. Its presence in such a high latitude indicates an inflow of warm water.

Pearcey: 338, 342, 417, 421 (frequency not stated).

200. **Globigerina triloba**, Reuss (F 305) (SG 277) (A 457).

Three stations: 286, 421, 447.

Frequent and large at St. 447, smaller at St. 421. Only two small specimens at St. 286.

Pearcey: 342 "few".

201. **Globigerina inflata**, d'Orbigny (F 306) (SG 278) (A 459).

Two stations: 313, 447.

A single large specimen at St. 313; frequent at St. 447.

Pearcey: 342 "fairly common".

202. **Globigerina dutertrei**, d'Orbigny (F 307) (SG 279) (A 460).

Six stations: 313, 417, 418, 421, 438, 447.

Frequent at Sts. 417 and 418, rare or very rare elsewhere.

Pearcey: 286, 300, 313, 338, 342, 387, 417, 418, 420, 421, 447 "in smaller or greater numbers".

203. **Globigerina conglomerata**, Schwager (F 308) (SG 280) (A 461).

Five stations: 312, 313, 417, 418, 447.

Common at St. 417, frequent to rare elsewhere.

This is almost certainly the species recorded by Pearcey under the name *G. dubia*, Egger, "rare" at St. 421.

204. **Globigerina pachyderma** (Ehrenberg) (F 310) (SG 281) (A 464).

Eleven stations: 226, 286, 300, 312, 313, 338, 417, 418, 421, 422, 447.

Very common at St. 421; common at Sts. 417 and 447; frequent at Sts. 286, 313, 418 and 422; very rare elsewhere, sometimes only a single specimen. Abnormal specimens such as those referred to in SG, p. 120, and A, p. 175, were observed at Sts. 417, 421, 422 and 447.

Pearcey: 300, 313, 338, 342, 387, 417, 420 "more or less abundantly".

Genus **Pullenia**, Parker and Jones, 1862

205. **Pullenia sphaeroides** (d'Orbigny) (F 315) (SG 286) (A 467).

Four stations: 286, 417, 421, 447.

Common at Sts. 421 and 447, where both the type and a compressed variety occur together. The spherical type is unusually large at St. 447; the compressed form is always smaller than the type.

Pearcey: 342, 420, 421, 447 "sparingly".

206. **Pullenia subcarinata** (d'Orbigny) (F 316) (SG 287) (A 468).

Three stations: 417, 421, 447.

Rare at all stations. At Sts. 417 and 421 all the specimens were of the compressed *quinqueloba* type, but the number of chambers varied from five to seven. At St. 447 both this form and the typical inflated *P. subcarinata* occur together, and with intermediate variations.

Not recorded by Pearcey within the convergence under either specific name.

Genus **Sphaeroidina**, d'Orbigny, 1826

207. **Sphaeroidina bulloides**, d'Orbigny (SG 289) (A 469).

One station: 417.

One typical specimen of average size. This is a great southward extension of the distribution of the species by 7° latitude, and is evidence of the penetration of warm water into the extreme south of the Weddell Sea.

Family ROTALIIDAE

Subfamily *ROTALIINAE*

Genus **Discorbis**, Lamarck, 1804

208. **Discorbis globularis** (d'Orbigny) (F 331) (SG 294) (A 474).

One station: 406.

A single typical specimen from 1131 fathoms, off Coats Land.

Genus **Cibicides**, Montfort, 1808

209. **Cibicides refulgens**, Montfort (F 355) (SG 303) (A 487).

One station: 417.

A single typical specimen. The rarity of the species, usually abundant in Antarctic material, is probably due as much to the nature of the bottom as the depth.

210. **Cibicides lobatulus** (Walker and Jacob) (F 356) (SG 304) (A 489).

Three stations: 406, 417, 421.

A single normal specimen at St. 406. At St. 417 the species is rare, but present both in the typical form and in the pauperate variety figured and described from deep water in the Drake Strait (A 489). Very rare and weak at St. 421.

Pearcey: 342, 447 "sparingly". He also records its variety *Cibicides* (*Truncatulina*) *tenuimargo* (Brady) "sparingly" at St. 417. I did not observe this.

211. **Cibicides wuellerstorfi** (Schwager) (F 361) (SG 306) (A 492).

Two stations: 417, 418.

Common at St. 417: frequent at St. 418.

Pearcey: 300, 417, 420, 421 "sparingly".

212. **Cibicides aknerianus** (d'Orbigny) (F 362) (SG 307) (A 493).

One station: 417.

Only a single specimen.

213. **Cibicides pseudoungerianus**, Cushman (F 363) (SG 308) (A 494).

Three stations: 417, 421, 447.

Frequent at all stations, but the specimens are small at St. 447.

Pearcey: 313 "sparingly" under the name *Truncatulina ungeriana* (d'Orbigny).

Genus **Globorotalia**, Cushman, 1927

214. **Globorotalia crassa** (d'Orbigny) (F 376) (SG 317) (A 500).

One station: 301.

A single small specimen.

Pearcey: 342 "few".

Genus **Eponides**, Montfort, 1808

215. **Eponides umbonatus** (Reuss) (F 386) (SG 322) (A 502).

Five stations: 286, 417, 418, 421, 447.

Common and large at St. 421; frequent at Sts. 417, 418 and 447; very rare at St. 286.

Wherever the species is at all abundant, both the type of Reuss and the thin-walled form described by Brady as *Truncatulina tenera* (see F 386) are found together in varying proportions, and with intermediate variations. At St. 421 the type predominates and grows to a much larger size than *tenera*. At Sts. 417 and 418 *tenera* predominates and all specimens are rather undersized. At Sts. 286 and 447 *tenera* was not observed.

Pearcey records the forms separately, but did not find the type *umbonatus* within the convergence. *Truncatulina tenera* is recorded as "rare" at Sts. 342, 417.

216. **Eponides karsteni** (Reuss) (F 391) (SG 324) (A 503).

Three stations: 338, 417, 421.

Extremely rare: only a single specimen at each station.

Pearcey: 447 "rare".

217. **Eponides weddellensis**, sp.n. (Plate I, figs. 65–67).

Three stations: 286, 417, 421.

Test minute, biconvex, the dorsal side exhibiting 3–4 convolutions is higher than the ventral and has five chambers in the last convolution; sutures distinct, flush, their white colour contrasting with the hyaline texture of the chambers; peripheral edge rounded; ventral side exhibiting only the five chambers of the last convolution; sutures depressed; aperture a minute slit on the inner edge of the final chamber on the ventral side.

Breadth about 0·16 mm. Height about 0·12 mm.

Fairly frequent at all three stations, the best specimens at St. 421. The species also occurs at St. 459, outside the convergence, and may have a wide distribution in deep water. Owing to its minute size it would be easily overlooked.

This little species is probably allied to *E. karsteni* (Reuss) and closely resembles the small form of that species figured by Brady from Magellan Straits (B. 1884, FC, pl. cv, fig. 8), which is common in many deep-water deposits from the North Atlantic and elsewhere. But it differs in having an unbroken peripheral edge, and never has the ventral peripheral line shown in the Challenger figure.

218. **Eponides exiguus** (Brady) (F 387) (SG 323) (A 504).

Five stations: 286, 417, 418, 421, 447.

Only a single specimen at St. 286, but frequent to common at the remaining stations.

Pearcey: 342 "few", 417 "common", 447 "few".

219. **Eponides tumidulus** (Brady) (F 366) (SG 312) (A 505).

Four stations: 286, 417, 421, 447.

Rare, except at St. 421, where good specimens were frequent.

220. **Eponides bradyi**, Earland (F 367) (SG 313) (A 506).

Six stations: 286, 300, 313, 421, 422, 447.

Common at Sts. 286 and 421 and frequent at St. 447, rare at the remaining stations. The best specimens, i.e. those in best condition, were observed at Sts. 313, 421 and 447, but the majority of the specimens at all stations were dead and often decomposing shells.

Pearcey records the species under the name *Truncatulina pygmaea*, Hantken, at Sts. 300, 342, 420 and 447 "few".

Genus Laticarinina, Galloway and Wissler, 1927

221. **Laticarinina pauperata** (Parker and Jones) (SG 326) (A 509).

One station: 417.

Two large, dead and rather worn, specimens.

Genus Rotalia, Lamarck, 1804

222. **Rotalia orbicularis** (d'Orbigny) (A 511).

One station: 421.

A good and typical specimen.

223. **Rotalia soldanii**, d'Orbigny (F 394A) (SG 328) (A 512).

Two stations: 417, 447.

Frequent at both stations, and exceptionally large at St. 417.
Pearcey: 342 "common", 447 "rare".

Family NUMMULINIDAE

Subfamily *NONIONINAE*

Genus Nonion, Montfort, 1808

224. **Nonion pompilioides** (Fichtel and Moll) (F 402) (SG 333) (A 515).

Three stations: 338, 421, 447.

Frequent at St. 447, rare at the other stations.
Pearcey: 286, 342, 447 "sparingly".

225. **Nonion stelliger** (d'Orbigny) (F 404) (SG 335) (A 516).

One station: 418.

Two weak specimens only.
Pearcey: 417 "a few specimens".

226. **Nonion scapha** (Fichtel and Moll) (F 407) (SG 338) (A 520).

Two stations: 312, 417.

Extremely rare and far from typical. The few specimens found are so asymmetrical that they are almost inseparable from *Nonionella iridea* (No. 227). I am convinced that *Nonionella* has no zoological value as a genus.

Genus Nonionella, Cushman, 1926

227. **Nonionella iridea**, Heron-Allen and Earland (F 410) (SG 339) (A 522).

Three stations: 312, 417, 418.

Frequent at Sts. 417 and 418; a single specimen at St. 312.

I cannot think how Pearcey can have overlooked this little form or its closely allied relative *Nonion scapha*, with which he might have confused it, the two species being zoologically very nearly akin.

Genus Elphidium, Montfort, 1808

228. **Elphidium excavatum** (Terquem) (F 413) (A 525).

One station: 338.

Two small specimens from St. 338 in the Scotia Sea, but not recorded in the Weddell Sea.

Pearcey does not record any species of *Elphidium* within the convergence.

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REPORT ON SOME CRYSTALLINE COMPONENTS OF THE WEDDELL SEA DEPOSITS

By F. A. BANNISTER, M.A.

With chemical analyses by M. H. HEY, M.A., B.Sc.

Assistant Keepers in the Mineral Department of the British Museum (Natural History)

(Plates II, II *A*)

During his study of the Foraminifera present in oceanic bottom samples brought back by the Scotia Expedition (1902–4) from the Weddell Sea, Mr A. Earland picked out a number of minute crystals and crystalline nodules which he separated by external characters into three groups. A brief description of these crystalline components and an account of their examination by optical and X-ray methods seemed desirable chiefly because the substances identified have not hitherto been recorded from ocean bottom deposits.

HYDRATED CALCIUM OXALATE, $CaC_2O_4 . 2H_2O$

The first group consists of minute "envelope" crystals recorded from a number of stations in the very deep water of the central Weddell Sea, from depths of 2425–2739 fathoms (4434–5008 m.) (Plate II, fig. 1). These crystals are transparent, colourless, tetragonal bipyramids varying in size from 0·2 × 0·1 to 0·3 × 0·15 mm. When immersed in a liquid and viewed under the microscope they present sharp, square outlines with well-marked diagonals showing the intersection of the four uppermost pyramid faces. Intergrowths of two or more individuals are not uncommon but the grouping appears to be accidental and not in conformance with any twin-law. The "envelope" crystals are sparsely distributed in the deep-sea deposits. A gram of unpicked material from St. 286 yielded about fifty crystals weighing only half a milligram, the mineral residue consisting principally of fragments and rounded pebbles of clear, colourless quartz. Fragments of green hornblende, pink almandine, orange hessonite, brown biotite and glauconite were also detected.

When examined with convergent polarized light each "envelope" crystal gives a positive uniaxial figure consisting of a black cross surrounded by two interference rings; approximate birefringence = 0·02. If monochlorobenzene be used as the immersion liquid the crystal outline completely vanishes; hence the refractive index $\omega = 1{\cdot}523 \pm 0{\cdot}005$. The specific gravity could not be determined by balancing in a mixture of bromoform and benzene owing to their minute size and lack of colour. Several, however, were mounted on thin glass fibres and each in turn accurately centred in a parallel beam of light restricted in diameter by an iris diaphragm and pin-hole collimator. By such means it was possible to measure the angle between pyramid faces. The average value for the angle between a pyramid face r and the basal plane c (001) is $cr = 30° 35'$.

At this stage the tetragonal symmetry of a crystal was confirmed by a Laue photograph taken with the X-ray beam passing along the c axis [001]. Rotation photographs

were also taken with a square edge vertical (Plate II, fig. 3), with a diagonal vertical and also about the *c* axis [001] (Plate II, fig. 4). The smallest tetragonal unit cell which can be assigned to the crystals on the basis of these photographs has the dimensions *a* 12·40, *c* 7·37 ± 0·02 Å. The indices of the pyramid faces are therefore {101}. The calculated axial ratio is $c : a = 0{\cdot}594 : 1$ corresponding to a calculated *cr* angle = 30° 42½′, in close agreement with the goniometric value, 30° 35′. Rotation and oscillation photographs about the [100] axis were then indexed and the unit cell found to possess the symmetry of the space-group $C_{4h}^5 = I\,4/m$.

The optical and crystallographic data so far obtained show that the crystals cannot be identified with any known tetragonal mineral. Fortunately, determinative data for all organic and inorganic substances known to possess tetragonal symmetry have recently been compiled by Hey,[1] and independently by J. D. H. Donnay and J. Mélon (1934). These data follow the determinative method suggested by T. V. Barker (1930). Allowing a possible error of ± 1° in the measured *cr* value, fifteen compounds are found to have *cr* values ranging from 29½ to 31½°. Several of these are soluble in water and therefore are excluded; of the remainder only the salt commonly known as calcium oxalate trihydrate, $CaC_2O_4 . 3H_2O$, possesses the same appearance and optical properties as the crystals under consideration. The *cr* value tabulated by Donnay and Mélon for $CaC_2O_4 . 3H_2O$ is 30° 7′. The presence of calcium in the deep-sea crystals was readily confirmed by dissolving one in a drop of dilute sulphuric acid and obtaining gypsum needles. A test for the oxalic acid radicle would, however, have consumed most of the crystals so far separated from the Weddell Sea deposits; certainly a complete chemical analysis was out of the question.[2]

A less direct method of confirming the above identification was therefore sought. The methods described by A. Souchay and E. Lenssen (1856) for synthesizing $CaC_2O_4 . 3H_2O$ did not promise a product sufficiently pure for chemical work. "Envelope" crystals are also present in the cells of certain plants (A. W. P. Zimmerman, 1892), and in the gall and urine of many mammals and fish. No reference, however, has yet been found to crystals of plant or animal origin measuring more than 0·17 mm. across, so that a separation of the requisite amount for exact chemical analysis would probably be impossible. It was suggested by Mr Hey that larger crystals of the compound might constitute the coating of certain renal calculi. This suggestion proved valuable. At the invitation of the Curator of the Royal College of Surgeons I was permitted to examine all their specimens of renal calculi taken from human bladders. Two calcium oxalate calculi were found coated with platy crystals, and these were kindly loaned to the Mineral Department for investigation.

The calculi differ somewhat in appearance; one, catalogue number C. 90, is spherical in shape, diameter 25 mm., and has a white powdery surface encrusted with white translucent platy crystals with clear edges. The second calculus (an unregistered duplicate) is roughly ellipsoidal in shape, measures 25 × 15 mm., and is encrusted with pale brown crystals of the same type. The matrix like that of C. 90 is white but more compact. Golding Bird (1842) has described similar renal calculi from the Guy's Hospital

[1] Unpublished. [2] The crystals weigh approximately 1×10^{-5} gm. each.

Museum collection. He identified the calcium oxalate crystals with the much smaller "envelope" crystals found in human urine. "Sometimes these crystals are opaque and the octahedron is remarkably flattened: the calculus then looks as if studded with pearl-spar." His careful study shows that the calcium oxalate may be intergrown with uric acid, sodium urate, ammonium urate, magnesium ammonium phosphate, calcium phosphate or calcium carbonate. Golding Bird does not give, however, the dimensions of the renal crystals of calcium oxalate. The crystals of both the calculi I have examined are roughly square in outline, measuring 2–3 mm. across, but the pyramidal faces are curved and the thickness of the crystals varies considerably owing to subparallel growth and possibly twinning. Only small transparent wedge-shaped fragments suitable for optical and X-ray work could be detached from the edges. These give a positive uniaxial picture and yield approximate refractive indices ω 1·523, ϵ 1·544 (Becke method). The broken fragments exhibit no well-marked cleavage directions; their hardness is about 4, Mohs' scale. Light reflections from the pyramid faces show that their curvature is due to the presence of a large number of vicinal faces between (101) and (001). A few crystal fragments give values *cr* varying from 30° 1′ to 30° 56′, but natural faces are too imperfect for refractive index measurements by the prism method and the fragments are too small to be ground and polished. Gypsum needles crystallized from a solution of a crystal fragment in sulphuric acid, and the residual liquid also decolorized a drop of potassium permanganate solution. These preliminary measurements and chemical tests therefore suggested the identity of the deep-sea crystals and the crystals from the renal calculi.

X-ray rotation photographs of some crystal fragments from both the renal calculi were then taken about the supposed [100] axis, i.e. about an edge of a square plate. All the spots of each photograph correspond exactly in position and intensity with those of a similar photograph of a deep-sea crystal. These photographs constitute the most reliable test of the identity of the two compounds since they do not depend upon the perfection of crystal form but only upon the atomic arrangement within a crystal. A chemical analysis of carefully selected fragments from the renal calculi should therefore reveal the chemical composition of the deep-sea crystals.

The specific gravities of crystal fragments from both calculi were separately determined by balancing in mixtures of bromoform and benzene. Values varying from 1·98 to 2·00 were obtained, but no systematic difference could be detected between the specific gravities of the white and pale-brown crystals. The first chemical analysis on white crystals, sp. gr. 1·99, from C. 90, gave CaO 37·3 per cent (by ignition), C_2O_3 46·1 per cent (by titration with potassium permanganate solution), H_2O 16·7 per cent (loss of weight at 270° C.), total 100·1 per cent, which corresponds to a chemical formula $CaC_2O_4 . 1\frac{1}{2}H_2O$ and was the first indication that the usually accepted trihydrate formula might be incorrect. The formula relating the specific gravity d, atomic contents nM and unit-cell dimensions of a tetragonal compound is $nM \times 1{\cdot}648/a^2c = d$. Since X-ray rotation photographs of the deep-sea crystals and renal calculi crystals are identical the values a 12·40, c 7·37 Å. may be inserted in the above formula. The value of M corresponding to $CaC_2O_4 . 1\frac{1}{2}H_2O$ is 155, the observed specific gravity is 1·99, so that

$n = 1{\cdot}99 \times 12{\cdot}4^2 \times 7{\cdot}37/155 \times 1{\cdot}648 = 8{\cdot}82$. Hence it appears that the tetragonal unit cell contains approximately $9CaC_2O_4 . 1\frac{1}{2}H_2O$. The crystal-structure of oxalic acid and many oxalates have now been worked by W. H. Zachariasen (1934) and S. B. Hendricks (1935). In all of them the C_2O_4 group has constant shape and dimensions. Both the unit-cell dimensions and the space-group of the renal calculi crystals would lead us to expect an even, not an odd number of C_2O_4 groups per unit cell. It is difficult in the face of the X-ray evidence to imagine how more than eight C_2O_4 groups can be accommodated. Therefore either the observed specific gravity or the chemical composition or both are inconsistent with the X-ray data.

In the meantime it had been found that the powdery material forming the matrix of the renal calculi crystals effervesces when dissolved in dilute acids and gives a reaction for phosphate. This is also true of the crystals themselves, probably due to fine-grained inclusions of the matrix. Moreover, a small residue of organic tissue remains after solution of a calculus crystal or matrix in acid. The first analysis on the white crystals must therefore be rejected, since it is clear that the presence of organic matter would disturb the permanganate titration and give too high a value for the oxalate content. The phosphate content of the crystals is also appreciable and possibly due to admixture of the calcium oxalate salt with dahllite, $3Ca_3(PO_4)_2 . CaCO_3$. The latter constituent is extremely fine-grained and attempts to separate sufficient from the crystals for optical tests or from the matrix for chemical analysis proved unsuccessful.

Two further chemical analyses were now made on pale-brown crystals, sp. gr. 1·99, from the unnumbered calculus. It is impossible to determine the water content directly since the crystals when dried at 270° C. still contain about 6 per cent H_2O and if the temperature is raised above 270° C. the oxalate begins to decompose. Nor can the oxalate be determined by titration with potassium permanganate owing to interference by included organic tissue. Accordingly the powdered crystals (10·06 mg. for analysis 1, 14·115 mg. for analysis 2) were weighed into a small crucible, dried at 270° C., heated at 580° C. to decompose the oxalate, reweighed and then ignited at 950° C. The residue was weighed and the phosphate content determined as ammonium phosphomolybdate. The ignitions at 580 and 950° C. correspond to the following reactions:

(*a*) Hydrated calcium oxalate + dahllite $\xrightarrow{580^\circ C.}$ $CaCO_3 + Ca_3(PO_4)_2 + CO + HO_2$.

Loss of weight due to evolution of $CO + H_2O$.

(*b*) $CaCO_3 + Ca_3(PO_4)_2 \xrightarrow{950^\circ C.} CaO + Ca_3(PO_4)_2 + CO_2$.

Loss of weight due to evolution of CO_2.

Table I gives the results of the two analyses, together with the recalculated figures allowing for deduction of dahllite. Table II shows that the two recalculated analyses correspond approximately to $CaC_2O_4 . 2H_2O$. The observed specific gravity 1·99 should also be corrected for a content of 4 per cent dahllite, see Table I. Assuming a specific gravity 3·1 for the latter constituent, the corrected value for the renal calculi crystals is 1·94. The specific gravity calculated from the X-ray data and assuming that the tetragonal unit cell contains $8CaC_2O_4 . 2H_2O$ is 1·91. The chemical and X-ray data are there-

fore in fair agreement considering the indirect methods used for analysis. There is no doubt that the usually accepted trihydrate formula for the tetragonal calcium oxalate is incorrect, and there is at least a strong probability that the formula should be $CaC_2O_4 . 2H_2O$.

Table I. *Chemical analyses of renal calcium oxalate crystals, sp. gr.* 1·99

Observed percentages				Equivalent to				Recalculated to 100 % after deduction of dahllite		
CaO	P_2O_5	Loss at 580° C.	Loss at 950° C.	Dahl-lite	CaO	CO_2	$CO+H_2O$	CaO	CO_2	$CO+H_2O$
37·46	1·78	37·34	23·42	4·32	35·10	23·24	37·34	36·61	24·24	39·15
36·81	1·75	36·22	25·22	4·24	34·50	25·04	36·22	36·03	26·14	37·83

Table II

	Analysis 1	Analysis 2	Mean	Theoretical percentage for CaC_2O_4		
				H_2O	$2H_2O$	$3H_2O$
CaO	36·61	36·03	36·32	38·39	34·18	30·80
CO_2	24·24	26·14	25·19	24·15	26·81	31·50
CO	—	—	—	15·38	17·06	19·17
H_2O	—	—	—	29·67	21·95	12·33
$CO+H_2O$	39·15	37·83	38·49	45·05	39·01	31·50

It is interesting to note that this conclusion is in agreement with the results of the earliest workers (T. Graham, 1838). No completely satisfactory analysis of the salt, however, has yet been published. A. Frey (1925), who claims to have produced artificial crystals $\frac{1}{2}$ mm. across, records a figure for the water content only and deduces the formula $CaC_2O_4 . 3H_2O$. It is not, however, obvious with what measure of success he separated the tetragonal salt from associated products of crystallization. His optical data are also at variance with mine; he gives ω 1·552, ϵ 1·583, presumably measured on the artificial salt and it is significant that these values are close to those that would be observed for a crystal of whewellite, $CaC_2O_4 . H_2O$, lying on the face x (011), viz. γ' 1·551, α' 1·592. In view of this disagreement in refractive index measurements some of his identifications of the tetragonal crystals in plants must be accepted with reserve.

Many references to the presence of calcium oxalate in the waste products of plants and animals also record the size of the "envelope" crystals. C. Schmidt (1846) studied their formation in yeast covered by beer for many days. He also detected them in the gall of rabbit, dog and pike. The crystals usually measured 0·01 × 0·005 mm. and were never greater than 0·03 mm. across. Frey has observed crystals definitely of the tetragonal form in *Begonia* species of size 0·023 × 0·013 mm. They are also a usual constituent of human urine especially during the summer months. A sample of urine of patients suffering from oxaluria kindly sent to me by Mr L. W. Proger, Pathological Curator of the Royal College of Surgeons, shows many "envelope" crystals 0·02–0·025 mm. across, refractive index $\omega = 1·52$. Golding Bird (1843) made a microscopic and chemical study of "envelope" crystals in human urine and was the first worker to

record their low birefringence and approximate refractive index. It is also clear that he recognized and was puzzled by the difference in optical properties of the "envelope" crystals and of the dumbbell-shaped spherulitic aggregates of whewellite sometimes found in urine. Apparently he did not suspect the existence of two hydrates of calcium oxalate. The largest envelope crystals detected in human urine by Golding Bird (1843) measured 0·056 mm. across, but he found still larger light amber crystals, 0·17 mm. across in horse urine (1845). These he preserved dry since they were "invisible in canada balsam".

Although the deep-sea crystals are about ten times larger than those observed in plant cells and ten times smaller than those from renal calculi, they are only a little larger than urine crystals. The possibility that the deep-sea crystals have been deposited from the urine of some marine organism is unlikely for three reasons. (i) Crystals deposited from urine might well be expected in all oceanic bottom deposits, whereas Mr Earland's extensive study of ocean bottom deposits from all over the world so far shows that the "envelope" crystals are not only a minor constituent but are restricted to very deep water in the Weddell Sea. (ii) Louis Heitzmann (1934) has observed that urine and renal crystals of calcium oxalate turn black at first on slow ignition owing to included organic tissue. The deep-sea crystals, however, change to calcium carbonate and at a higher temperature to lime without change of colour. (iii) The deep-sea crystals possess sharp edges and faces free from scratches so that there seems little doubt that they were formed *in situ*. It is obviously important to continue the search for calcium oxalate crystals in other ocean bottom deposits. The more urgent problem of the constitution of the blue and red sea-bottom muds may have led mineralogists to overlook this rare constituent. It is essential to make a careful study of oceanic deposits before removing the calcium carbonate by digestion with dilute hydrochloric acid, since this treatment would also remove calcium oxalate.

Although the monoclinic hydrate, $CaC_2O_4.H_2O$, the more commonly observed salt in plants (raphides) (Vesque, 1874) occurs as the mineral whewellite in coal measures from various localities, the tetragonal salt has not hitherto been observed as a mineral. H. Braconnat (1825) has indeed recorded a growth of lichen on limestone containing nearly half by weight of calcium oxalate and J. Liebig (1853) named a similar incrustation, thierschite. Neither author, however, gives figures for the water content and I have not been able to secure a specimen of the original material for identification. A section of a lichen spore reveals irregularly shaped crystals which, however, prove to be whewellite not the tetragonal salt. Thierschite should then be regarded as an uncertain species since the name was given to the material on the basis of an incomplete chemical analysis. It would also be unwise to give a mineral name to the tetragonal crystals of hydrated calcium oxalate from the Weddell Sea deposits until the dihydrate formula is placed beyond question.

The origin of calcium oxalate in the ocean bottom mud of the central Weddell Sea is entirely conjectural. The writer finds it impossible to suggest how any sedimentary constituent of the earth's crust can be restricted to one small region, more particularly

when that constituent is widely distributed in small quantities in numerous living organisms. It is easier, however, to offer reasons for the formation of the tetragonal salt rather than whewellite in very deep water, given a suitable concentration of calcium oxalate. Frey has found that the "envelope" crystals are most stable in alkaline solutions containing a high calcium content, and that their stability is also favoured by immersion in viscous media. H. Wattenburg (1933) has observed the variation of specific alkalinity with depth of water in the south Atlantic ocean. It is interesting that his records for many stations show a marked increase in alkalinity between 4000 and 5000 m., corresponding with a slight "undersaturation" of calcium carbonate. Hence the formation of tetragonal calcium oxalate crystals at depths of 4434 to 5008 metres in the Weddell Sea may be favoured by a similar increase in specific alkalinity of the ocean bottom water and by the viscosity of the enclosing muds.

GYPSUM, $CaSO_4 . 2H_2O$

The second group of crystals received from Mr Earland consists of two samples from different stations: St. 428, 66° 57′ S, 11° 13′ W, 2715 fathoms (= 4965 m.), and St. 391, 66° 14′ S, 31° 18′ W, 2630 fathoms (= 4809 m.). These are lenticular crystals up to $2{\cdot}0 \times 1{\cdot}0 \times 0{\cdot}5$ mm. in size which are readily shown by optical properties, specific gravity and chemical tests to be gypsum (Plate II, fig. 2). The crystal forms present are (111) and (110), only the latter being transparent. The faces (111) are corroded and the crystals resemble much larger crystals of similar form observed by Baret (1888) and others from saline deposits. Crystals identical in form but smaller in size have also been separated from ocean bottom samples brought back by the Discovery Expedition from the Weddell Sea in 1925. These latter crystals, which were found by Mr E. Heron-Allen, F.R.S., come from St. WS 553, 63° 33¾′ S, 60° 33½′ W, 5029 m. Gypsum has not hitherto been recorded from ocean bottom deposits and it is to be noted that this constituent, like calcium oxalate, would be removed at least partially by initial treatment of the sediments with acid. Since gypsum is one of the first minerals to be deposited when samples of sea water are evaporated (J. Usiglio, 1849) its formation in deep-sea deposits is of great interest. J. H. van't Hoff (1912) has studied the conditions of formation of gypsum in the Stassfurt salt deposits. There beds of gypsum, $CaSO_4 . 2H_2O$, and anhydrite, $CaSO_4$, form the lowest layers. The temperature of transition of gypsum to anhydrite under ordinary conditions is 63·5° C. The pressure due to 5000 metres of sea-water is about 500 atmospheres and the consequent lowering of the transition temperature about 25° C. Since the temperature of sea-water at such depths is approximately −2° C. the formation of calcium sulphate as crystals of gypsum rather than anhydrite is not surprising. The perplexing fact is that so common a mineral should not be found in other contemporary ocean-bottom samples; that indeed its distribution is governed by conditions, as far as we know, peculiar to the Weddell Sea. A knowledge of these conditions would probably throw light upon other problems of the Weddell Sea and would form a useful addition to oceanography (see I. Igelsrud, 1932).

EARLANDITE, $Ca_3(C_6H_5O_7)_2 . 4H_2O$

The third group of crystalline constituents differs completely from the calcium oxalate and gypsum crystals. They were separated from fine and coarse samples from St. 417, 71° 22′ S, 16° 34′ W, 1410 fathoms = 2580 m. consisting chiefly of quartz grains, foraminifera, etc. The fine samples also contain a moderate number of pale yellow to white nodules $\frac{1}{2}$–$1\frac{1}{2}$ mm. in diameter, with a warty surface, whilst the coarse samples yielded some larger nodules up to 2 mm. in diameter and a few fragments up to 3 mm. across, obviously portions of the crusts of still larger but hollow nodules (Plate II *A*, fig. 1). Of particular interest were a nodule attached by siliceous cement to the wall of a specimen of the foraminifer *Rhabdammina linearis*, Brady (Plate II *A*, fig. 2) and another nodule which had been incorporated with other mineral grains in the tube of a marine worm. The discovery of these two specimens by Mr Earland places entirely beyond doubt the fact that this third crystalline component is also of deep-sea origin and has not resulted from accidental contamination of the sea-bottom samples. Both large and small nodules are polycrystalline and very fine-grained $< 10^{-4}$ mm. They vary in specific gravity from 1·80 to 1·95 and the aggregate refractive index of crushed nodules is 1·56. X-ray powder photographs of a nodule of sp. gr. 1·80 and another of sp. gr. 1·95 are identical (Plate II *A*, fig. 3) but quite different from powder photographs of the tetragonal and monoclinic hydrates of calcium oxalate. Nevertheless the nodules give a definite reaction for calcium, dissolve in dilute acid and decolorize potassium permanganate solution. They must therefore be composed of a calcium salt of an organic acid other than oxalic acid. Efforts were then made to establish the identity of the nodules by comparison with other insoluble calcium salts of organic acids known to exist in plant cells. Both calcium tartrate and calcium malate have been recorded as plant constituents (A. Zimmerman, 1892) but powder photographs of both artificially prepared salts are found to be quite different in pattern from the powder photograph of the nodules from St. 417. Since citric acid is present in many fruit juices Mr Hey suggested that calcium citrate, a very insoluble salt, should also be compared. Powder photographs of the artificially prepared salt and the deep-sea nodules are identical (Plate II *A*, fig. 3). Moreover, the specific gravity of the artificial salt is 1·951, i.e. identical with the highest observed specific gravity of the nodules and the aggregate refractive index is the same for both, viz. 1·56. The artificial salt shows a marked tendency to spherulitic formation, but the individual crystal plates are sufficiently large to yield single crystal X-ray photographs. Since crystallographic and optical data for calcium citrate are not recorded in the literature we hope to publish measurements on single crystals at a later date.

By the courtesy of Dr E. Hope the Dyson Perrins laboratory, Oxford, undertook the microchemical analysis of the deep-sea nodules and obtained the results given in Table III.

Mr Hey also made residue determinations on two separate samples of nodules and on artificially prepared calcium citrate. The chemical work confirms the X-ray

determination and shows that the nodules have a composition close to the theoretical composition of hydrated calcium citrate, $Ca_3(C_6H_5O_7)_2 . 4H_2O$. The departures are probably due to adsorbed water and small variable amounts of impurities. A spectrographic examination of the residue left after ignition of the second sample (4·075 mg.) studied by Mr Hey shows in addition to calcium, traces of strontium, barium, magnesium, manganese and iron; also minute traces of copper (Plate II *A*, fig. 4). No

Table III. *Chemical analyses of earlandite,* $Ca_3(C_6H_5O_7)_2 . 4H_2O$, *from St.* 417, *Weddell Sea, and of artificial calcium citrate*

	Dyson Perrins earlandite	Theoretical	M. H. Hey		
			Earlandite		Artificial calcium citrate
C (%)	24·01	25·24	—	—	—
H (%)	3·48	3·18	—	—	—
CaO (%)	28·63	29·48	31·6	29·01	29·70
Material used: mg.	3·601	—	1·816	4·075	526·2

impurity (except perhaps magnesium) amounts to more than 0·01 per cent, e.g. the phosphorus (probably present as phosphate) cannot be detected with certainty by ordinary chemical methods. The nature of the small amounts of impurities in the calcium citrate nodules is additional evidence that the nodules were formed at the sea-bottom (J. V. Samoilov, 1917). Their distribution is even more restricted than calcium oxalate and gypsum, and their origin is equally conjectural. So far as is known this is the first reported occurrence of calcium citrate in nature. We therefore propose to name the new mineral *earlandite* in recognition of Mr Arthur Earland's long-continued contributions to the study of ocean deposits.

SUMMARY

Three crystalline components from the ocean bottom of the Weddell Sea have been identified as crystals of calcium oxalate dihydrate, $CaC_2O_4 . 2H_2O$, crystals of gypsum, $CaSO_4 . 2H_2O$, and polycrystalline nodules of calcium citrate, $Ca_3(C_6H_5O_7)_2 . 4H_2O$, for which the name earlandite is proposed. X-ray photographs of the deep-sea crystals of calcium oxalate show that the unit tetragonal cell has dimensions a 12·40, c 7·37 Å. and possesses the symmetry of the space-group $C_{4h}^5 = I\,4/m$. Crystals from renal calculi yielding identical X-ray photographs are found to have the probable composition $CaC_2O_4 . 2H_2O$. Both the deep-sea and renal calculi crystals are identical with, but larger than "envelope" crystals found in the waste products of many plants and animals. The trihydrate formula usually given to the "envelope" crystals is incorrect.

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PLATE I

Fig. 1. *Pelosina cylindrica*, Brady (No. 16): ×4. (The drawing is reversed, the base being at the top.)

Figs. 2–4. *Sigmoilina obesa*, Heron-Allen and Earland (No. 10): ×26. Figs. 2, 3, side views. Fig. 4, oral end view.

Fig. 5. *Vanhoeffenella gaussi*, Rhumbler (No. 15): ×26.

Fig. 6. *Proteonina tubulata* (Rhumbler) (No. 26): ×26.

Figs. 7–9. *Keramosphaera murrayi*, Brady (No. 13). Fig. 7, general view: ×26. Fig. 8, a broken specimen showing roughly concentric layers: ×26. Fig. 9, a portion of the unworn external surface showing apertures of the tubular chamberlets: ×50.

Figs. 10, 11. *Thurammina corrugata*, sp.n. (No. 30). Fig. 10, a broken specimen reconstructed from fragments showing internal and external surfaces: ×26. Fig. 11, a young and unbroken individual: ×45.

Figs. 12, 13. *Thurammina cariosa*, Flint (No. 35): ×26. Fig. 12, an individual specimen. Fig. 13, a double specimen.

Fig. 14. *Thurammina favosa*, Flint (No. 33): ×26. Sessile on sand grain.

Figs. 15, 16. *Haplophragmoides weddellensis*, sp.n. (No. 66): ×26. Fig. 15, side view. Fig. 16, edge-oral view.

Figs. 17, 18. *Haplophragmoides sphaeriloculus*, Cushman (No. 67): ×26. Fig. 17, side view. Fig. 18, edge-oral view.

Fig. 19. *Hormosina normani*, Brady (No. 60): ×6.

Figs. 20–22. *Recurvoides contortus*, Earland (No. 74): ×45. Figs. 20, 21, side views. Fig. 22, edge-oral view.

Figs. 23, 24. *Ammobaculites agglutinans* (d'Orbigny) (No. 75): ×26. Side views.

Figs. 25, 26. *Cyclammina pusilla*, Brady (No. 101): ×26. Fig. 25, edge-oral view. Fig. 26, side view.

Figs. 27, 28. *Cyclammina orbicularis*, Brady (No. 100): ×18. Fig. 27, edge-oral view. Fig. 28, side view.

Figs. 29–31. *Cyclammina contorta*, Pearcey (?) (No. 99). Fig. 29, side-oral view: ×26. Fig. 30, side view: ×26. Fig. 31, side view: ×15. All three specimens more or less worn and showing cancellated structure.

Figs. 32–34. *Trochammina soldanii*, sp.n. (No. 92): ×26. Fig. 32, edge view. Fig. 33, dorsal surface. Fig. 34, ventral surface.

Figs. 35–37. *Spirolocammina tenuis*, Earland (No. 103): ×45. Side views.

Figs. 38–40. *Miliammina arenacea* (Chapman) (No. 104): ×45. Fig. 38, front view. Fig. 39, rear view. Fig. 40, oral-end view.

Figs. 41, 42. *Lagena alveolata*, Brady, var. *separans*, Sidebottom (No. 127): ×45. Fig. 41, side view. Fig. 42, edge view.

Figs. 43, 44. *Lagena alveolata*, Brady, var. *substriata*, Brady (No. 128): ×45. Fig. 43, edge view. Fig. 44, side view.

Fig. 45. *Lagena clavulus*, Heron-Allen and Earland (?) (No. 135): ×70.

Fig. 46. *Lagena desmophora*, Rymer Jones (No. 137): ×70.

Fig. 47. *Lagena laevis* (Montagu) (No. 152): ×70. Variety with basal spines.

Figs. 48–50. *Lagena lamellata*, Sidebottom (No. 155). Fig. 48, specimen with outer layer almost entirely denuded, showing inner spinous layer: ×70. Fig. 49, specimen with outer layer almost intact: ×70. Fig. 50, a fragment of the outer layer of plates supported on minute spines: ×70.

Figs. 51–53. *Lagena marginata* (Walker and Boys) var. *echinata* (Seguenza) (No. 160): ×70. Figs. 51, 52, side views. Fig. 53, edge view.

Figs. 54, 55. *Lagena orbignyana* (Seguenza) (No. 164): ×45. Fig. 54, edge view. Fig. 55, side view.

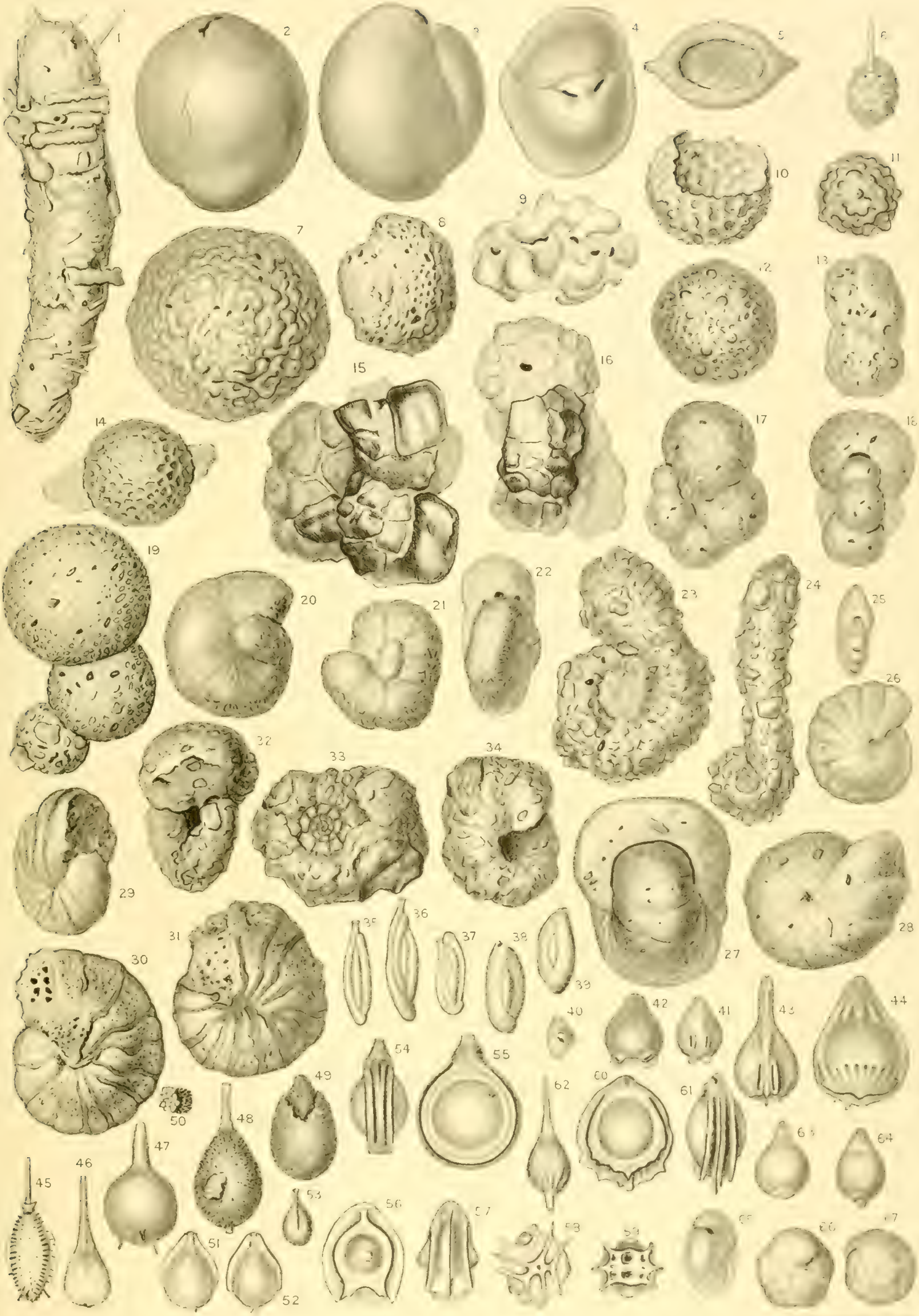
Figs. 56–59. *Lagena orbignyana* (Seguenza) var. *walleriana*, J. Wright, var. (No. 165): ×70. Fig. 56, side view. Fig. 57, edge view. Fig. 59, basal view. Fig. 58, oral end view of a trigonal specimen.

Figs. 60, 61. *Lagena orbignyana* (Seguenza) var. cf. *alata*, Cushman (No. 164): ×45. Fig. 60, side view. Fig. 61, edge view.

Fig. 62. *Lagena stelligera*, Brady var. (No. 175): ×70.

Figs. 63, 64. *Lagena stelligera*, Brady, var. *eccentrica*, Sidebottom (No. 176): ×45. Fig. 64, variety with basal spine.

Figs. 65–67. *Eponides weddellensis*, sp.n. (No. 217): ×95. Fig. 65, edge-oral view. Fig. 66, ventral view. Fig. 67, dorsal view.



FORAMINIFERA FROM THE WEDDELL SEA

PLATE II

Fig. 1. Envelope-shaped crystals of hydrated calcium oxalate, $CaC_2O_4 . 2H_2O$, from the Weddell Sea ('Scotia', St. 286, 4550 m.). ×15.

Fig. 2. Lenticular crystals of gypsum, $CaSO_4 . 2H_2O$, from the Weddell Sea ('Scotia', St. 391, 4809 m.). ×10.

Figs. 3 and 4. X-ray photographs of a crystal of hydrated calcium oxalate from the Weddell Sea. Both photographs were taken with unfiltered copper radiation and with the same cylindrical camera diameter 6·04 cm. A length of 8·5 cm. on the original films is equal to 10 cm. on the reproduced figures. Fig. 3 shows the photograph obtained when the crystal is rotated about the [100] axis. Fig. 4 is the corresponding photograph for the [001] axis.

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4

CRYSTALS FROM WEDDELL SEA DEPOSITS

PLATE II A

Fig. 1. Nodules of earlandite, $Ca_3(C_6H_5O_7)_2.4H_2O$, from the Weddell Sea ('Scotia', St. 417, 2580 m.). ×8.

Fig. 2. Nodules of earlandite attached by siliceous cement to the wall of *Rhabdammina linearis*, Brady. ×14.

Fig. 3. X-ray powder photograph of a nodule of earlandite, taken with unfiltered copper radiation and with a cylindrical camera, diameter 6·04 cm. A length of 10 cm. on the original film is equal to 10 cm. on the reproduced figure.

Fig. 4. Portion of the spectrographic record from wave-lengths 4200–6000 Å. A quartz spectrograph fitted with a Hartmann diaphragm was used giving accurately aligned spectra of: *A*, carbon arc alone; *B*, R.U. powder; *C*, residue left after ignition of 4·075 mg. earlandite (see Table III). R.U. (Raies Ultimes) powder consists of small quantities of fifty-one elements diluted so that only the 'Raies Ultimes' (i.e. the most important or sensitive lines) appear in the electric arc.

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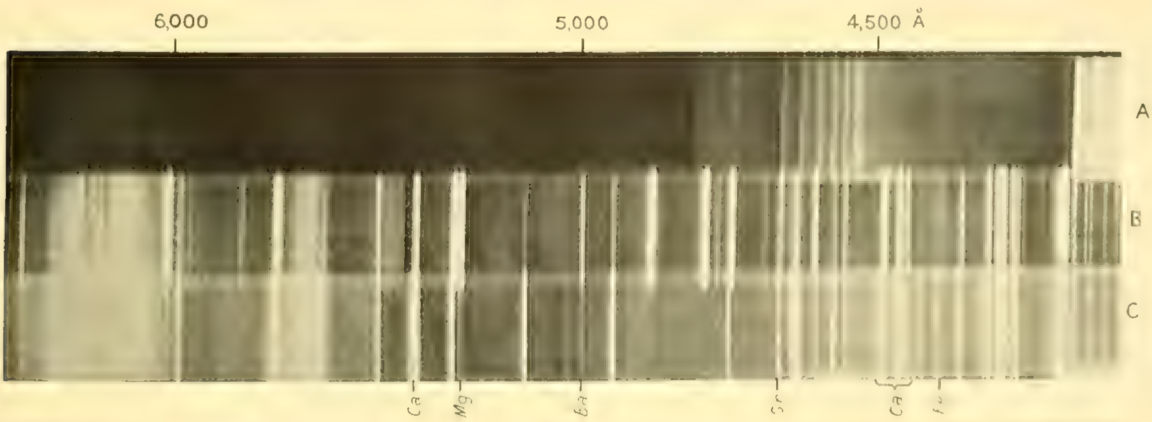

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CRYSTALS FROM WEDDELL SEA DEPOSITS

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THE ROYAL RESEARCH SHIP 'DISCOVERY II'

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THE ROYAL RESEARCH SHIP 'DISCOVERY II'

By R. A. B. Ardley, R.N.R., and N. A. Mackintosh, D.Sc.

(Plates III–XIII; Text-figures 1–5)

INTRODUCTION

The R.R.S. 'Discovery', of which an account appeared in Vol. I of the *Discovery Reports*, returned to England in October 1927, at the end of her first commission. It was originally intended that she should sail south again to continue her investigations in regions where a steel ship would not be suitable. Before definite plans were made, however, it became known that a wooden ship would be needed for the British Australian New Zealand Antarctic Expedition under Sir Douglas Mawson, and in 1928 the Australian Government came forward with a proposal to charter the 'Discovery' for this purpose. The experience gained during her employment by the Discovery Committee had shown that the researches which it was most important to prosecute as the next stage of the investigations lay in the open ocean. They could be carried out far more expeditiously in a ship of greater speed and range of action, and did not call for the unique strength of hull which rendered the 'Discovery' so suitable for the coastal exploration to be undertaken by Sir Douglas Mawson.

The Discovery Committee, in view of these considerations, accepted the Australian offer and obtained sanction from the Secretary of State for the Colonies for the construction of a new ship with greater speed and cruising radius. Since encounter with ice would only be incidental to the continuation of the ship's work, it was decided that a steel ship would be preferable to a wooden one, being more economical and allowing better accommodation. Experience gained by the whaling factories in recent years had shown that it was practicable for a strengthened steel ship to penetrate light Antarctic pack-ice. With a full-powered steam vessel observations over a wide area could be carried out more efficiently, as full advantage could be taken of weather suitable for the operations, and better accommodation provided for the scientific work. Strengthening of the hull was provided to increase the safety of the ship in any pack-ice necessarily met with in the course of her work.

The ship, which has been named 'Discovery II', was specially designed for the work in prospect. She is a single-screw steamship of 1036 tons gross (displacement 2100 tons at a draught of just under $17\frac{1}{2}$ feet), with triple expansion engines developing sufficient power to give a maximum speed of $13\frac{1}{2}$ knots on trials and an economic speed of 10 knots. The following special features are embodied in her design:

(i) Closely spaced frames forward, and double plating of the bow down to the forefoot and along the water-line, with wood panting stringer and ice compression beams in the forehold.

(ii) Large bunker capacity for fuel oil, allowing a cruising range or endurance of about 8000 miles at full speed and some 10,000 miles at economic speed.

(iii) Auxiliary deck machinery specially designed for various branches of scientific research.

(iv) In the accommodation—a biological and a physical and chemical laboratory, a laboratory for simple and rough work, a dark room and various storerooms for scientific gear, all these being specially adapted for the work.

The vessel has a complement of fifty-two when carrying a scientific staff of six.

The 'Discovery II' first sailed for the Antarctic in December 1929, and since then has been continuously employed in the investigations undertaken by the Discovery Committee. The first commission lasted from 1929 to 1931, during which period her work was mainly in the waters of the Dependencies of the Falkland Islands and in the South Atlantic sector of the Antarctic. During her second commission (1931–3) her voyages included a complete circumnavigation of the Antarctic continent, in the course of which W- or V-shaped cruises, between the ice-edge and warmer waters, were carried across the southern parts of the Indian, Pacific and Atlantic Oceans. Voyages in the third commission (1933–5) were mainly in the Atlantic and Pacific sectors of the Antarctic, and included several long zig-zag cruises in the vicinity of the pack-ice. Recently the ship sailed again on her fourth commission.

Throughout these years the 'Discovery II' has been found admirably suited to the work for which she was designed. Encounters with the most adverse weather conditions have proved her to be thoroughly seaworthy, and in facilities for the scientific work she has risen to all expectations.

The account of the vessel which follows owes much, particularly in the sections dealing with construction, to a very careful revision undertaken by the late Mr A. Harker, of Messrs Flannery, Baggallay and Johnson, Ltd., shortly before his untimely death.

CONSTRUCTION AND DESIGN

The plans and specifications of the ship, her machinery and equipment were drawn up by Messrs Flannery, Baggallay and Johnson, Ltd., acting under the instructions of the Crown Agents for the Colonies, and the contract for her building was placed on February 6, 1929, with Messrs Ferguson Brothers, of Newark Works, Port Glasgow, who submitted the most favourable tender. The ship was launched on November 2, 1929, with steam up, practically ready for trials.

The principal dimensions of the vessel are:

Length, overall	234 ft.
Length at load water-line ...	220 ft.
Breadth, moulded	36 ft.
Depth, moulded	20 ft.
Load draught, designed mean	16 ft.
Load draught, Lloyd's summer freeboard	17 ft.

The appearance and design of the ship are illustrated in Plates I–III. She is of flush deck type (the upper deck being the strength deck) with a raised forecastle and half poop. She has a straight stem down to about 1 ft. above the load water-line, where the stem runs away in a long fair curve to the keel. This cut-away forefoot improves her steering qualities and is of assistance in breaking light pack-ice. In section the stem is rabeted or T-shaped, affording protection to the edges of the plates in ice navigation. The fore body of the ship is well flared out from the water-line to the gunwale for about 40 ft. aft from the stem (i.e. to the end of the topgallant forecastle), this form being intended to guard against the shipping of heavy water when working in a head sea. The ship, in fact, has proved herself remarkably dry for her size when hove-to. The form of the hull is rather fine. The ship has a good rise of floor, and a round bilge with a very slight tumble-home from the load water-line to the upper deck—a large tumble-home would have been inconvenient in handling scientific gear.

The stern is of the ordinary elliptical counter type, which is well adapted for shooting large nets, and in conjunction with the raised poop has proved its seaworthy qualities when running before sea and wind. The main strength members of the ship's hull are of specially heavy construction, the stem, keel and sternpost all being well in excess of classification requirements for vessels navigating in ice. In addition to this strong framework, the frames in the fore body of the ship are closely spaced and very deep, and a series of cross-beams consisting of pitch pine timbers of 12 by 12 in. section are fitted at frequent intervals extending aft for about 50 ft. from the stem. The ends of the beams are housed in a pitch pine panting stringer about 7 ft. below the main deck. The combination of stringer and beams at normal water-line affords a valuable resistance against ice. The other main ice protection is formed by a doubling of the shell plating fore and aft along the water-line and all round the bow to the height of the upper deck. The beams to the upper deck are fitted on every frame to increase the rigidity of the structure.

The rudder is of large area and heavy construction, much in excess of classification requirements; it proved to be very effective, for the ship carries her steerage way under ordinary conditions until she is practically stopped. Six transverse bulkheads are fitted, two oiltight and four watertight. The main deck is of pitch pine; the upper deck is of steel, sheathed with $2\frac{1}{2}$-in. pitch pine, and both bridge decks are of teak. Bilge keels are fitted amidships for about one-third of the vessel's length. They are constructed of T-bar and bulb plate, so arranged that in the event of the projecting bulb plate being damaged it will become detached from the T-bar with the minimum risk of damaging the ship's plating.

ARRANGEMENT OF FITTINGS AND ACCOMMODATION (Plates III–V)

The whole of the upper deck is protected by bulwarks 3 ft. 6 in. high, capped with a teak rail and provided with wash-ports to allow free outlet for any water shipped. Two hinged doors in the bulwarks, one on each side, are fitted in the waist to form gangways for the accommodation ladder.

All the davits and small winches for operating scientific gear are placed along the port side of the ship, and all refuse outlets and discharges are led, so far as practicable, to the starboard side to prevent rubbish from fouling the nets.

On the topgallant forecastle, at the stem head, there is a pedestal for seating a 20-in. searchlight, an alternative position for the searchlight being provided on a steel platform fitted at the foot of the fore topmast just beneath the crow's nest. Recently the 20-in. searchlight has been superseded by twin 10-in. Admiralty searchlights mounted on the navigating bridge. Twelve feet abaft the stem on the port side of the forecastle is the Lucas sounding machine, driven by a three-cylinder Brotherhood steam engine. This position was found to be satisfactory, as it is sufficiently far removed from the after machine to allow nets to be worked during sounding operations without danger of the wires from the two machines becoming foul. On the starboard side, level with the Lucas machine, is a light harpoon gun, with which some of the smaller species of whale can be captured. It is a small gun, mounted on a swivel and firing larger harpoons than could be carried in a shoulder gun. Just forward of the break of the forecastle is the deep hydrological reel and davit (Plate X, fig. 2), used entirely for obtaining temperatures and water samples from depths below 500 m. A full description of these fittings is given below in the section on equipment. The usual bollards and fairleads are provided, and a capstan, worked by a vertical spindle from the windlass below deck, occupies the centre of the forecastle, with a telegraph and speaking tube for communication with the windlass operator. Controls are also provided on the forecastle deck for handling the windlass and capstan. A stout breakwater, V-shaped in plan, and lightly canted forward from its base, is fitted near the after end of the forecastle head: this throws off much of the water shipped over the bows. Abaft this are carried two mooring wire reels, and the spare bower anchor. The forestay is provided with hanks and carries a large fore staysail.

Beneath the forecastle head, right forward, is a small ready-use deck store. The centre of the space in the forecastle is taken up by the windlass, which is of heavy construction and was made to special design by Messrs Clarke, Chapman and Co., Ltd. It is used for working the anchors and cables, which are considerably larger than Lloyds' requirements for the size and service of the ship. The upper end of the hawse pipes open on deck just abaft the bulkhead of the deck store, and patent cable stoppers are fitted between the hawse pipes and the windlass. Abreast the windlass on the starboard side is a paint locker, with the crew's washhouse abaft it. Next to the washhouse are the crew's lavatories, entered direct from the upper deck and having no communication with the forecastle space. These compartments are tiled. On the port side, forward, is a bench and abaft this is a drying room, fitted with steam pipes and racks. Adjoining the drying room and occupying the after end of the port side is the crew's galley, containing an oil-fuel range and the usual galley fittings. This galley can be entered either from the forecastle space or from the upper deck.

The forecastle space is enclosed by a steel bulkhead and entered by teak doors, one on either side. Between these doors, forward of the steel bulkhead, is a companion way

leading to the crew's quarters, light being admitted by a small port above the companion. A small hatchway is provided forward of the windlass for access to the forepeak store and compartments below.

FOREDECK (Plates IV, V)

The forward part of the upper deck between the break of the forecastle and the bridge is clear of deckhouses. The foremast is placed 6 ft. abaft the forecastle bulkhead and carries a large crow's nest 60 ft. above the water-line, with the searchlight platform just beneath it. A square sail yard, hoisted on a traveller on the fore side of the mast, is crossed for the purpose of carrying a large square foresail. The yard is generally carried in reserve, housed alongside the mast. Abreast of the foremast on the starboard side is a large reel carrying 600 fathoms of $2\frac{3}{4}$-in. mine-sweeping wire intended for anchoring in deep water. This reel can be driven by a messenger from the windlass drum-end, through the starboard forecastle door.

The centre of the foredeck is occupied by the fore hatch, fitted with a portable steel cover which is bolted down at sea. The cover carries six watertight hinged skylights which provide the main ventilation and lighting for the officers' accommodation below. The hatch gives access to the fore hold where all the food, clothing and canteen stores are carried. The gaff of the fore trysail is used to work stores through this hatch.

Abaft the hatch, on the port side, wood chocks are provided for carrying a Norwegian pram; and on the starboard side a potato locker, capable of carrying five tons, was constructed during the first commission in the position formerly occupied by a dinghy. A large watertight wooden locker, used for preserving specimens of Cetacea in salt, occupies the space close to the bulwark abreast of the potato locker. On the port side, just forward of the bridge, are two davits and reels and an auxiliary engine for making scientific observations (Plate X, fig. 1).

LABORATORIES AND DECK HOUSES AMIDSHIPS (Plates IV, V)

The open fore deck leads aft in two alleyways to a position near the middle length of the vessel, and from this point communication aft is continued by inside alleyways between the engine- and boiler-room casings and the inboard bulkheads of the deckhouses, abaft the stokehold fiddley, which here extend right out to the waterways along the ship's side. Two hinged steel breakwaters, 3 ft. high, are fitted abreast the forward ends of the laboratory deckhouses, and can be used as gates to close the forward ends of the outside alleyways in rough weather.

Between the two outside alleyways, on the upper-deck level, are the main scientific laboratories, with an entrance lobby, entered from either side of the ship. Of the space provided, the biological laboratory (Plate VIII) occupies about two-thirds, and is situated on the starboard side. It is separated from the smaller hydrological laboratory (Plate IX, fig. 1) by a fore and aft wooden bulkhead.

The laboratories are entered from the lobby by large double doors, and in each of them there is also a door opening directly on to the deck. These outside doors, like all

others throughout the ship, are of heavy pattern, strongly made of doubled teak and insulated. The doors of the laboratories and lobby are exposed in the waist of the ship, and it was found impossible to keep them watertight in heavy weather. To overcome this difficulty special portable steel storm doors are provided for clamping over the teak doors during bad weather.

The lobby, which is panelled in light oak, is provided with small settees in the two forward corners, while the two after corners are divided off by steel bulkheads. On the port side aft is a small room with wash basin for officers' use, entered from the lobby, and here a door is fitted giving access under cover to the after part of the vessel. This is an emergency door only required in heavy weather when the watertight doors in the screen bulkheads are closed. On the starboard side are two officers' lavatories, which are entered from the deck. The central part of the lobby is occupied by double staircases, one leading up to the wardroom and the other down to the officers' accommodation.

Abaft the lobby and between it and the boiler casing is placed the ship's galley, entered from either side by halved steel doors and fitted with an oil-fuel range with two ovens and the usual galley equipment.

The stokehold doors, also of steel, adjoin the galley, and immediately abaft the stokehold entrance are transverse bulkheads, pierced by doors which give access to the internal alleyways leading aft.

The two square spaces on each side of the galley and stokehold entrances were found to be difficult to negotiate in heavy weather, being situated just in the waist where the ship has least freeboard, and bulkheads have since been built extending diagonally across from the after corner of the lobby. The bulkheads are fitted with hinged storm doors and readily throw off any heavy water that may come on board. The enclosed space abaft the bulkheads has been found very useful for the storage of meat and ready-use galley stores.

The two blocks of houses abaft the stokehold, outside the covered alleyways, are subdivided by steel bulkheads into spaces which are put to a variety of uses. On the starboard side, commencing forward, is the ship's office, with the usual fittings and with the canteen opening from it. Immediately abaft the canteen is the petty officers' lavatory, while the after space on this side is fitted as a net store. On the port side, forward, is a small compartment originally intended for galley stores; but since the construction of the bulkheads enclosing the galley spaces it has been converted into a carpenter's shop, and now contains benches, a vice, and racks for carpenter's tools. Next to the carpenter's shop is the instrument store (p. 97), and abaft of this store is the petty officers' bathroom. The after compartment of the port side block is the largest of all, and is arranged as a laboratory (Plate IX, fig. 2), with one door opening into the alleyway and another on to the after deck.

In the alleyway on the starboard side is a fire locker built into the engine-room casing and fitted with a hydrant and storage space for a supply of Foamite. The Foamite is provided for extinguishing oil fires, but the hydrant can also be used as an ordinary fire main.

The engine-room casing is entered by steel doors, one on each side. The after end of the casing is in the thwartship line of the two blocks of side houses and is partitioned off to form, on the starboard side, a companion way to the petty officers' mess, and on the port side a chamber containing the refrigerating plant.

AFTER DECK (Plates IV, V)

Abaft the engine-room casing, and separated from it by the thwartship alleyway containing the entrance door to the petty officers' mess, is a large steel house containing the main trawling winch (Plate XI). This winch, which is provided with two drums carrying 1000 and 5000 fathoms of wire rope, has been transferred from the R.R.S. 'Discovery' and has already been described,[1] but in the new vessel it was fitted with new ball-bearing traversing-gear leads and with steam controls on both sides of the house. The ends of the main shaft project through the house on either side and are provided with warping drums. The winch house and winch position are specially arranged to ensure that the operator, facing aft, has a full view of the operations and can give immediate response to signals. The after end of the house can be closed when required by large steel folding doors. A small auxiliary drum, with chain drive from the main shaft of the winch, stands just abaft the winch house on the starboard side.

The boat deck terminates in line with the after end of the winch house, and the rest of the after deck is open. The centre portion is occupied by the after hatch. This is of similar construction to the fore hatch; but only the after portion has a movable cover, and the fore part is fitted with watertight skylights, providing ventilation and lighting for the petty officers' mess. The movable after section gives access to the after hold.

Midway between the after hatch and the winch house is the mainmast, carrying a 3-ton derrick on its fore side for hoisting and lowering the motorboat, and a gaff for the free-footed mainsail on the after side. This gaff is also used to work the after hatch. A winch and davit, similar to those on the forecastle head, but used for working vertical plankton nets, are placed abreast the winch house on the port side (Plate XI, fig. 1).

Fairleads for the trawl warps and the usual bollards and mooring pipes are fitted.

The poop (Plate XII, fig. 1) is raised only 3 ft. above the upper deck and is approached by wide ladders on either side. In the middle line, about 6 ft. abaft the break of the poop, a powerful samson post is stepped, carrying a derrick capable of lifting 6 tons, which will plumb 6 ft. beyond the taffrail. This is used for working heavy deep-sea nets and trawls, and can also be used on the fore side of the post if necessary. Two roller fairleads are arranged, one on either side, in the bulwarks right aft, and for the rest the poop is quite clear of obstructions, a great assistance in the rapid handling of trawls and large tow-nets.

The poop space is entered by a small circular torpedo hatch on the port side, and is mainly occupied by the rudder-head, quadrant and steering engines, all of which are of very heavy construction for Antarctic service. The forward port corner of the space is divided off into a small lamp locker fitted with racks and oil tanks, and an open wooden

[1] Kemp, Hardy and Mackintosh, *Objects, Methods and Equipment*, Discovery Reports, I, pp. 160, 161.

locker originally intended for potatoes, but now used for deck stores, is placed just abaft the lamp locker. Hand steering gear is also provided and a screw quadrant brake; the space is too confined to permit the successful use of relieving tackles, although they are provided for use in emergency.

BOAT DECK (Plate IV)

The boat deck, communicating with the fore deck by a steel ladder on either side, and with the after deck by a teak ladder on the starboard side, carries the wardroom, sick bay, wireless room and boats. The wardroom house, of steel, extends the width of the ship, except for an alleyway on either side and across the fore end of the boat deck. It contains the wardroom and the wardroom pantry, which is a long narrow compartment set abaft the wardroom and communicating with it by a door. The wardroom (Plate VII, fig. 1) is entered from the boat deck by an insulated teak door on either side and from the lobby below by a double staircase. It is panelled in light oak, with furniture of the same wood, and contains two fore-and-aft tables with seating accommodation for twenty persons. Plenty of light is admitted by Stone's square windows placed on three sides, and there are two large steam heaters. In the after corners of the wardroom are two small alcoves on either side of the staircase: that on the starboard side is fitted with a settee and a small table and bookshelves, while on the port side is a wine locker. A sideboard is placed in the middle line against the fore bulkhead of the wardroom. The wardroom contains a series of pictures of earlier vessels which have borne the name 'Discovery'.

The pantry contains a sink, a hot press, a percolator and a milk emulsifying machine, with a lift communicating with the galley below. Teak outside doors on both sides of the pantry open on to the boat deck.

Immediately abaft the wardroom house are a galley skylight abutting on the pantry bulkhead, the funnel casing, two large stokehold ventilators, and a grating admitting light to the fiddley. The funnel is large and elliptical, and has a rake of $\frac{3}{4}$ in. per foot. Abreast of the funnel casing two 25-ft. lifeboats built to Board of Trade requirements are carried in ordinary drop chocks and manipulated by swing davits of standard pattern. Hinged steel engine-room skylights fitted with glass ports, together with engine-room ventilators, occupy the centre of the boat deck abaft the funnel casing, and immediately abaft the skylight casing is a steel deck house containing the sick bay and wireless room. Two 25-ft. Admiralty pattern whalers, equipped to Board of Trade requirements, and housed and hoisted in the same manner as the lifeboats, are carried on either side of the sick bay and wireless room. On top of the sick bay an 18-ft. part-decked motorboat with a 12 H.P. Parsons engine is carried athwartships in specially strengthened chocks, and the main derrick is used for hoisting the boat out and in.

The wireless room is entered from the port side by an insulated teak door, the operator's table and apparatus being arranged along the starboard side. The installation consists of a modern $1\frac{1}{2}$ kilowatt valve transmitting apparatus with a separate emergency installation which will give communication on medium wave-lengths. The ship is also

equipped with a short-wave transmitter and a combination receiving set with which wireless communication with England can generally be maintained: blind areas are occasionally found in the Southern Ocean in which both the despatch and receipt of long distance signals prove impracticable. A direction finder is fitted by which the ship can obtain her own position in relation to land stations and the position of other vessels in relation to herself.

The sick bay (Plate VII, fig. 3) consists of two compartments, a dressing room and the sick bay proper; these are separated from the wireless room by a steel bulkhead, and from each other by a fore and aft wooden bulkhead with a communicating door. The dressing room on the starboard side is the larger compartment and contains a settee, a sink, and a large medicine chest, together with a desk and a cupboard for the accommodation of medical stores. A Phillips X-ray outfit and a dental machine are provided. The sick bay itself contains two swing cots, one above the other, and a wash basin. The lighting of this house is by square wooden-framed drop windows, and both compartments have doors opening on to the boat deck. A narrow alleyway bounded by an open rail separates the after end of the sick bay from the break of the boat deck.

NAVIGATING AND FLYING BRIDGES (Plate IV)

The navigating bridge is situated immediately above the wardroom house, the deck extending to the ship's side and flush with the break of the boat deck forward. Teak ladders on either side, placed just abaft the wardroom doors, lead from the boat deck. The deck house on this bridge is of teak and contains the chart room, an echo-sounding compartment, the captain's cabin and a small survey office. Forward of this house and abutting on it is the wheel house or wheel shelter, eight feet wide and fitted with square drop windows on each side and in front. The wheel house is entered by sliding doors on either side and contains the wheel, Telemotor steering gear, steering compass, flag lockers, speaking tubes and a telephone to the wireless room. Two Kent's clear-view screens are fitted in the forward wheel-house windows to enable the officer of the watch to keep a good look-out in snowstorms and heavy weather, and at the angles of the bridge two 10-in. Admiralty searchlights are mounted. The bridge, at its fore end and for 10 ft. along each side, is protected by a teak panelled rail and the after end by an open rail covered with painted canvas. In the forward wings of the bridge are engine-room telegraphs with extensions to the flying bridge. On the starboard side, just beneath the ladder leading to the flying bridge, an electrically driven Kelvin sounding machine is fitted, and an electrically operated revolution indicator is placed on the port side. Flag lockers and a sanitary tank are placed abaft the house.

The chart room and echo-sounding compartment occupy the whole width of the forward section of the house. The chart room is 7 ft. wide; it has an insulated teak door on the starboard side, a door communicating with the echo-sounding compartment on the port side and two windows opening into the wheel house. It contains a large chart table with drawers below, a chronometer box, lockers for instruments, the receiving portion of the direction-finding apparatus and the recording dial of the Chernikeef log.

The echo-sounding compartment contains three echo-sounding machines and recorders of the Admiralty pattern, and the recording dial of the Munro anemometer. Further reference to the sounding machines is made below on p. 102.

On the starboard side, abaft the chart house, and communicating with it by a sliding door, is the captain's cabin, which is panelled in light oak, and on the port side is a small compartment used as a survey office.

The flying bridge extends above the house on the navigating bridge, with wings running out to the ship's side at the fore end. It is reached by a teak ladder on either side. It is protected by a teak-capped open brass rail covered with a painted canvas weather cloth and is generally used for coastal navigation and surveys, and sometimes for ice work, as a better view may be had from it over the forecastle head.

In the midship line, near the forward part of the flying bridge, is the standard compass, with a Kelvin 10-in. dry card. Abaft the compass is the aerial of the direction finder, the receiver for which is in the chart house below. Next aft is a stand for a metre range finder, and an ordinary ship's semaphore surmounted by a Morse flash lamp. On the starboard side, in the after corner of the bridge, is a 9-ft. range finder, which is used in running surveys. On the port side is the vane of the Munro anemometer, the dial of which is in the echo-sounding cabinet. A portable chart table is carried close to the forward rail on the same side.

MAIN DECK (Plate V)

Between the stem and the collision bulkhead, a fore-peak storeroom is provided forward of the chain locker; access to both these compartments is by a hatchway in the upper deck.

The crew's quarters, entered by a companion from the forecastle space, occupy the main deck between the collision bulkhead and the officers' accommodation. The mess deck is divided in the middle line and the half length of the flat by wooden partitions, the stokers occupying the smaller space which comprises the port after portion of the flat. In the seamen's mess deck wooden bunk accommodation is provided for sixteen men, and the usual lockers and tables are fitted. The stokers' mess has accommodation for six men.

The officers' accommodation (Plate VII, fig. 2) connects with the mess deck by means of a watertight door in the dividing steel bulkhead and contains fourteen cabins for officers and scientific staff, arranged along each side of the ship. At the forward end are two bathrooms, one on each side, fitted with calorifiers and wash-basins. Since the main deck is below load water-line the waste water is run into a sanitary tank and pumped over the side. The cabins are all of the single berth type and each is provided with a steam heater and an electric fan. There are no portlights in the main deck, but light is admitted into each cabin by stout double glass decklights. Ventilation is provided by brass screw mushroom vents to each cabin, but in heavy weather it was found difficult to keep these watertight, and in high latitudes they were always unshipped while at sea and the brass deadlights, provided for the purpose, screwed up in their places.

The after end of the officers' accommodation is bounded by the stokehold bulkhead, through which a steel watertight emergency door gives access to the stokehold on the starboard side. In the middle line aft is a large linen locker, and the double staircase, leading up to the laboratory lobby, abuts on the fore side of this linen locker. On the port side of the staircase is the cabin of the scientific officer in charge (Plate VII, fig. 4), which is larger than the other cabins and is panelled in oak.

The centre part of the officers' accommodation is partitioned off by wooden bulkheads to form a photographic room, with the door at the after end and a dark room leading from it.

Forward of the photographic room is the fore hold, which extends from the main oil tanks just abaft the coaming of the fore hatch to the collision bulkhead and down to the double-bottom tank tops. The square of the hatch and the wings in the way of it are clear, and the fore end is divided by wooden battens into tiers of lockers which are set apart for special stores such as medical, canteen, and clothing, while the main clear section is used for foodstuffs.

The petty officers' mess deck extends from the after engine-room bulkhead to the forward bulkhead of the after hold 'tween deck and, like the officers' accommodation, is divided into cabins along each side. Each of these cabins is arranged to accommodate two men, and the centre space of the flat is occupied by a long mess table. A pantry, with hot press and calorifier, occupies the port forward corner of the flat. Inboard of the pantry is a cold store, consisting of two separate freezing rooms and a small air-lock or handling chamber, in which boxes for making ice are fitted. Freezing is effected by an ammonia refrigerator arranged in a compartment built on to the after end of the upper deck as previously mentioned.

The after hold extends under the petty officers' mess deck, forward to the engine-room bulkhead and aft to the line of the poop front bulkhead. This hold is used only for scientific stores and is fitted with racks and bins for the storage of nets, bottle boxes and all kinds of scientific gear.

Throughout the ship all living quarters and enclosed spaces in which men may be required to remain for some considerable time are insulated on all surfaces exposed to sea or air. Thus in the officers' and petty officers' accommodation the outside walls of the cabins and the deckheads are insulated, and in the case of the deck houses, all outside bulkheads as well. This insulation, which has proved very effective, consists of fireproof cork slabs between the exposed surfaces of the bulkheads or decks and the inside panelling.

ENGINE ROOM

The machinery installation consists of a set of single-screw triple-expansion surface condensing machinery specially designed and constructed for service in the Antarctic and to contend with the low temperatures prevailing in these latitudes.

Particular attention has been paid to bearing surfaces, which are specially large to ensure the machinery working for long periods without adjustment.

The cylinders of the main engines are 18, $28\frac{1}{2}$, and $48\frac{1}{4}$ in. diameter respectively, having a common stroke of 28 in. The main engines are designed to develop about 1250 H.P. at 128 revolutions per minute. There are no pumps worked off the main engines, all pumps being independent. The strength of all shafting is well in excess of Lloyds' requirements, to ensure, so far as practicable, immunity from damage when encountering ice; this has already proved advantageous. The reversing gear is of Brown's make, direct-acting hand and steam type. An independent surface condenser is fitted with ample cooling surface to ensure a good vacuum in tropical waters when required. This condenser is constructed of mild steel and is of Messrs Weir's regenerative type.

An independent air pump of Messrs Weir's monotype, and a Weir's vacuum augmentor are fitted, the latter being intended for use more particularly when the vessel is passing through tropical waters. An independent auxiliary air pump is also fitted for harbour service. The circulating pump is of the centrifugal type and two independent engines are fitted, either of which has ample power for driving the pump.

The propeller shaft is of steel throughout, no liners being fitted, and the stern tube is provided with the builder's type of "Newark" oil-retaining device, enabling the shaft to be run in oil in white metal bushes. This arrangement has proved satisfactory; no rebushing has yet been carried out and the wear-down in the bushes has been found to be negligible. A steam coil is fitted round the stern tube for thawing purposes when low temperatures are encountered. The thrust block is of the single-collar Michell type having specially large surface.

The propeller is of the built type. It has a cast steel boss and four portable high-tensile bronze blades, the blades being of Messrs Stones' make, machined to pitch and specially strengthened for contact with ice.

The two feed pumps are of Messrs Weir's make with float regulators: either is capable of supplying the boilers at full power. A large general service pump is fitted for dealing with reserve feed water and other services, and this pump is also available for circulating the main condenser if required. A small general service pump is also provided for dealing with the sanitary service, wash deck and similar arrangements. An independent Duplex pump is fitted for dealing with the fresh-water service only. The evaporator and distiller are of Messrs Kircaldy's make, the evaporator having a capacity of 15 tons per 24 hours and the distiller capable of producing 10 tons of fresh water per 24 hours. The feed filter is of the gravity type with float control to Weir's pumps. A feed heater is also fitted, using the exhaust from the auxiliary machinery.

Lifting gear is provided in the engine room, together with large tanks for the storage of lubricating oil.

The boilers are two in number and of the ordinary cylindrical horizontal return-tube type. They have a working pressure of 200 lb. to the square inch. The diameter of the boilers is 13 ft. and their length is 11 ft., the total combined heating surface in both boilers being 3550 square ft. The furnaces are of Deighton's corrugated-section withdrawable type. Boiler mountings throughout are of gun-metal and of Messrs Dewrance's well-known make.

The oil-fuel installation is of the Wallsend-Howden type working in conjunction with Howden's forced-draught system. The oil-fuel pumps are of Messrs Weir's horizontal simplex type working in conjunction with Wallsend heaters. The forced-draught fan is fitted at upper-deck level in the engine room. It discharges to the boilers through a duct leading between the boilers, giving an equal distribution of air to each boiler. This arrangement of fan is found beneficial in assisting the ventilation of the engine room, and does not possess the disadvantage of being open to the stokehold.

A special feature in the machinery installation is the lagging of boilers and pipes. This is arranged not only to prevent condensation and heat losses, so far as may be possible, but also as a protection against freezing at the low temperatures in which the vessel is working. The general thickness of lagging on steam pipes is about $1\frac{1}{2}$ in., while on the boilers it is 3 in. The lagging makes the engine room and stokehold extremely comfortable under all conditions of working.

There is a small workshop at the port after end of the engine room. It is partitioned off from the engine room by a half-steel bulkhead, with expanded wire netting in the upper parts, so that the shop can be completely closed. The shop contains a 6-in. screw-cutting lathe of Messrs Drummond's make, a small shaping machine and a high-speed sensitive drill, in addition to a 12-in. diameter emery wheel. The usual equipment of benches, vices, shelves, lockers, etc., is provided. The whole of the machinery in the workshop is driven by an electric motor.

The electrical equipment consists of two independent generating sets. The larger set is capable of supplying power for the whole of the electrical equipment in the ship; the smaller set is intended for harbour use and general service, when lighting only and small calls on power are required. The larger generator has an output of about 28 kw. at 110 volts and is directly coupled to a compound two-crank steam engine of Messrs Sisson's make, the cylinder sizes being $6\frac{1}{2}$ and 9 in. with a common stroke of 5 in. This generator can supply current simultaneously for the whole of the lighting, fans, searchlight, wireless, refrigerator, workshop motor, floodlights on derricks and other electrical requirements. The smaller generator has an output of about 10 kw. at 110 volts, and is also directly coupled to a compound single-crank steam engine of Messrs Sisson's tandem type.

A large switchboard, of the enclosed type, is fitted at the level of the main-deck stringer, where it is well sheltered and all parts both back and front are readily accessible. The connections at the back of the board are all open and capable of being readily examined when required. The whole installation was carried out by Messrs J. Charters of Glasgow, and it has given very satisfactory service.

A full equipment of spare gear is provided for the main and auxiliary machinery, including spare propeller shaft and spare propeller blades.

The ship has a large bunker capacity; 316 tons of fuel oil are carried in bunkers which are divided by three fore and aft oiltight divisions into two main and two wing compartments. The usual subdivision of oiltight transverse bulkheads and fore and aft wash plates was not adopted for this ship, the arrangement fitted being considered safe in the

event of ice damage to the sides of the ship. This arrangement of oiltight bulkheads proved most satisfactory when on one occasion the side plating in way of the bunkers was badly damaged in the pack-ice, causing leakage in the wing bunkers. The centre compartment remained intact, leaving the ship with sufficient reserve of oil fuel to enable her to reach her destination. The bunkers extend from the after end of the fore hold to the stokehold bulkhead and are separated from the double-bottom fresh-water tanks by oiltight wells at either end. The starboard side of the forward well houses the sluice valve and hydrophone for the deep-water echo-sounding machine. The bunkers are fitted with steam coils for preheating the oil in cold weather, and permanent steaming-out pipes are fixed in each compartment.

On account of the long periods likely to be spent at sea, the ship is designed to carry approximately 140 tons of fresh water. Of this quantity about 10 tons is for drinking purposes and is carried in four rectangular galvanized steel tanks at the after end of the fore hold. The remainder is carried in the after peak ballast tank and in the fore hold, stokehold and engine-room double-bottom tanks.

At her trials on November 11, 1929, the vessel was tested over the measured mile in the Gareloch on the Clyde. She exceeded her contract speed of 13 knots and easily developed and maintained her designed horse-power of 1250. Her consumption at full speed is 12½ tons per day; with full bunkers this speed can be maintained for 25 days, giving a cruising radius of nearly 8000 miles. At an economic speed of 10½ knots her consumption is about 7½ tons per day. At this speed she can steam for 42 days and has a cruising radius of about 10,500 miles. In practice, however, her cruising range is considerably less than this, since, for the scientific work, the ship is normally hove to for several hours every day. During these hours the consumption of fuel is not much reduced although no distance is made.

SPECIAL ACCOMMODATION FOR RESEARCH

BIOLOGICAL AND HYDROLOGICAL LABORATORIES

The positions of the biological and hydrological laboratories, amidships on the upper-deck level, are shown in Plate V and they are illustrated in Figs. 1, 2 and Plates VIII, IX. The fore-and-aft bulkhead which separates them stops short of the common double-door entry in the after bulkhead, which thus allows open communication between the two. They receive natural light and ventilation by means of Stone's square pattern watertight windows of which there are seven in the biological and five in the smaller hydrological laboratory; they can be protected by mild steel storm shields in heavy weather. The laboratories are electrically lighted by ceiling lights, an adjustable bracket lamp over each of the working spaces on the benches and a large low hanging lamp over the swinging table in the centre of the biological laboratory. In both laboratories the walls are of white enamelled pitch pine, the bench tops of teak, and the chairs, cupboards and drawers of light oak.

Around the starboard and forward sides of the biological laboratory there runs a working bench at which there are four working places, three on the forward and one on the starboard side. Each is opposite a window and each has a chair with a swivel top which can be clamped in any position (Figs. 1, 2). Underneath the bench and between the chairs are tiers of small drawers. At the middle of the port side is a sink with taps supplying salt water, hot and cold fresh water, spirit and strong and weak formalin, and beside the sink is a vacuum connection from the main engine condenser which will give a vacuum equivalent to about 25 in. of mercury. Forward of the sink is a bench continuous with that of the forward side, with drawers and a card index to the library beneath a portion of it. On a shelf above the sink is a row of 5-litre aspirator bottles containing graded alcohols and preserving fluids, their taps protected by a brass guard rail. Above the bench forward of the sink are two 10-gallon cylindrical earthenware containers, one for strong and the other for diluted formalin. Each has an ebonite stopcock from which a rubber tube leads to an ebonite tap over the sink. A supply of 75 per cent spirit is kept in a 40-gallon tank abaft the flying bridge, and is piped down to another tap over the sink. On the after bulkhead is a large bottle rack for the storage of convenient numbers of all sizes of specimen jars, and below it are tiers of baize-lined drawers for small glass specimen tubes and miscellaneous apparatus. The bottle rack is similar to that described in *Discovery Reports*, I, p. 170.

A large gimbal table occupies the centre of the laboratory and is continuous at its after end with a bench which reaches a higher level and is fitted with drawer and cupboard space beneath. The swinging table is similar to that previously described (vol. I, p. 169), but is larger and has an enamelled iron guard-rail level with the table top, and a 75-lb. weight slung close to the deck. The bench on the after side of it has a detachable fiddle divided into compartments which fit specimen jars of all the sizes kept in stock. Part of the cupboard space beneath the bench is so designed that ten trays of $\frac{1}{2}$-lb. specimen jars can be taken out of their storage cases and used in it as drawers until the jars are filled and the trays replaced by others containing empty jars. A book-shelf of two tiers runs around the forward and the starboard sides of the laboratory above the windows.

A bench fitted to carry the burettes necessary for the analyses of sea water runs across the forward end of the hydrological laboratory (Plate IX, fig. 1). It has two working places, each opposite a window and each with a swivel-topped chair. On a high shelf on the inboard bulkhead above this bench are two 20-litre reservoirs of silver nitrate solution and one of sodium thiosulphate solution, the former for the determination of the salinity, the latter for that of the oxygen content of sea water. The titration of sea-water samples with silver nitrate solution is always done at the inboard working place, which is, for that reason, shut off from strong natural light by a blind over the window and a heavy curtain between it and the outboard working place and the other windows. Above the bench is the recording mechanism of a Negretti and Zambra distance thermograph, the thermometer bulb of which is in a pocket in the ship's hull at a point about 14 ft. below the surface. It gives a constant record of the temperature at that depth.

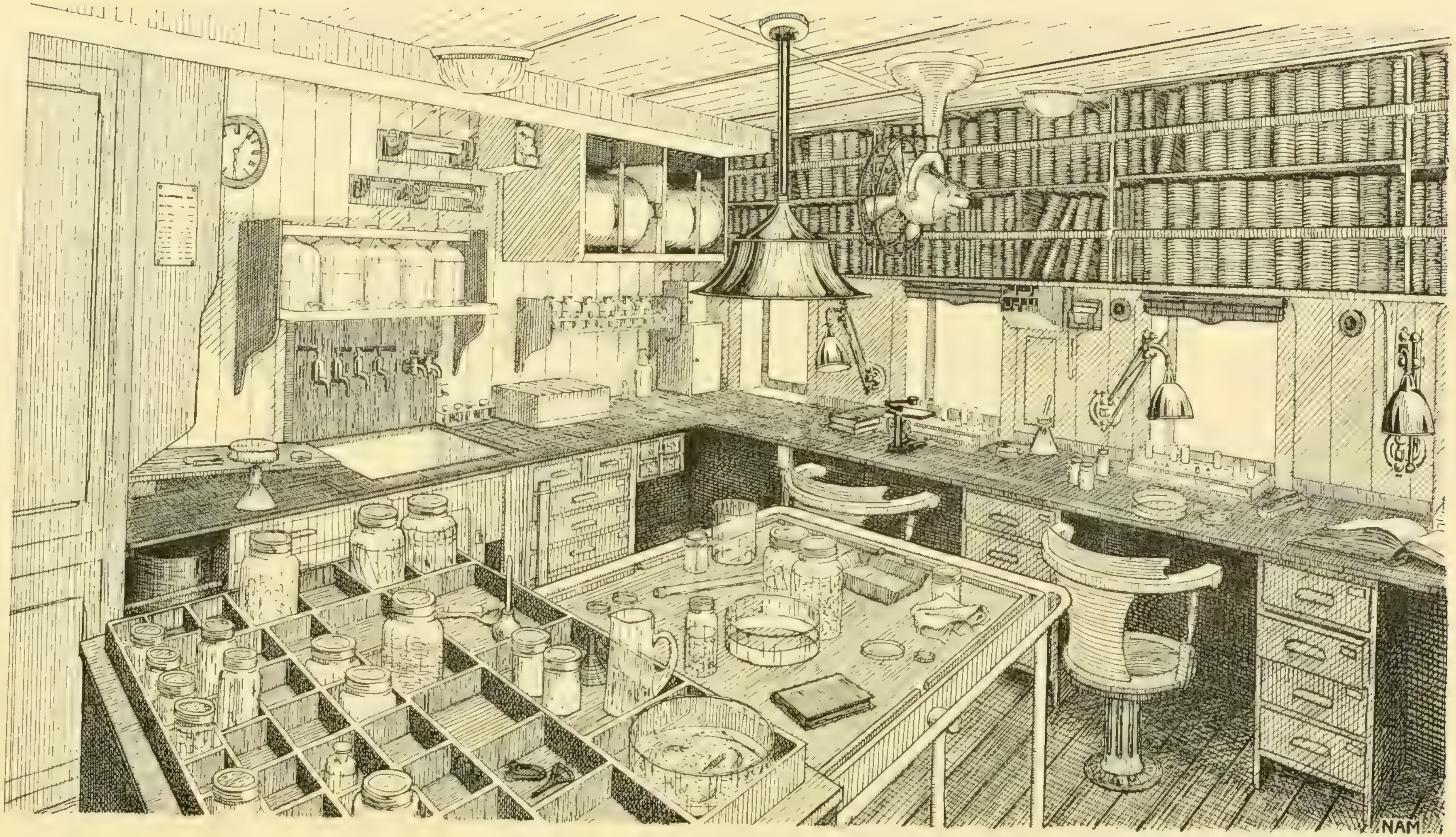


Fig. 1. The biological laboratory

On the starboard side of the laboratory is a bench and a sink, and drawers are fitted beneath the bench. The sink is supplied with hot and cold fresh water and cold salt water, and near the taps there is a vacuum connection from the engine room. The short section of bench forward of the sink is lead covered and has a drying rack above; aft of the sink it is of teak and is continued to the entrance from the biological laboratory. On it, near the sink, is stowed a 5-gallon copper container for distilled water, and a second similar container is stowed on a bracket on the outboard bulkhead abaft the bench.

On the port side of the hydrological laboratory there is another bench with a tier of drawers below it and some space for stowing boxes of water sample bottles. The bench

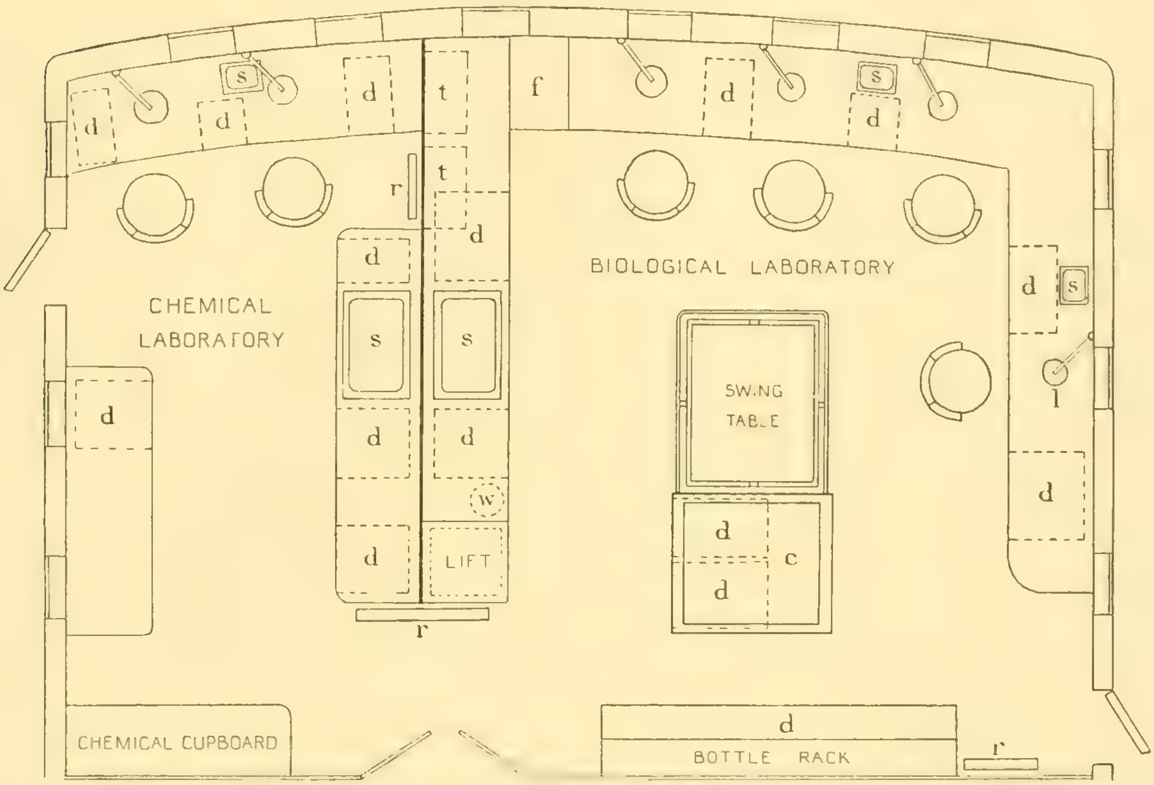


Fig. 2. Plan of biological and hydrological laboratories. *c*, cupboard under bench. *d*, drawers under bench. *f*, hinged flap of bench. *l*, bracket lamp. *r*, radiators. *s*, sinks. *t*, formalin tanks over bench. *w*, receiver for waste spirit under bench.

top is fitted with racks for the comparator tubes used in estimations of the phosphate, silicate and nitrate content of sea water. Along the after end of the laboratory is a large cupboard for the storage of chemicals with a fiddle on top for small Winchester bottles and other stores. Book shelves run along the port side above the windows.

In both laboratories there are numerous minor fittings which occupy most of the wall space. They include racks for burettes, pipettes, measuring cylinders, Petri dishes, glass bowls, labels, tubes and reagents. Three small gimbal tables suitable for holding open Petri dishes are swung on brackets from the bulkheads over the benches, and each working place has before it a rack for receiving large numbers of specimen tubes. In the

biological laboratory the microscope cases are screwed to the benches, and the microscopes themselves can be similarly secured.

Some further details of laboratory equipment are given later under "Laboratory Methods".

ROUGH LABORATORY

The rough laboratory is situated at the after end of the deck housing on the port side, conveniently near to the after vertical reel and the poop, from which nets are worked. It is a long narrow room, with one door opening to the after deck and another near its forward end to the port alleyway (Plate IX, fig. 2). A high bench for the keeping of deck log books, for the reduction, bottling and labelling of plankton samples and for the sorting of the catches of dredges and trawls, runs along the outboard side. Underneath it are drawers and open stowage space for the large trays and bowls used for sorting the hauls of dredges and trawls. At its forward end is a sink with salt water and hot and cold fresh-water taps. Above the sink is a 20-litre aspirator bottle containing weak formalin. Against the forward bulkhead on the inboard side is a gimbal table smaller than that in the biological laboratory and above it is a rack for 1 and 3 lb. jars—those most frequently used for the larger plankton samples.

On the inboard side there is a low cupboard in the after corner and running forward from it two long racks, the lower with circular holes for the stowage of the larger plankton net buckets, the higher for open glass jars used in plankton work. Forward of the lower rack and between it and the forward door is an electrical centrifuge.

On the bench there are racks for specimen tubes and for the three sizes of settling tubes which are sometimes used for concentrating plankton hauls; on the after cupboard there is a fiddle for the ½-lb. jars which are always used for small vertical plankton hauls. The laboratory is naturally lighted by three ports in the ship's side above the bench and electrically by two ceiling lights and a bracket lamp over the bench.

A speaking tube from the rough laboratory to the bridge has recently been fitted so that easy communication can be maintained between the scientific officer supervising the fishing of the nets and the officer of the watch handling the ship.

PHOTOGRAPHIC ROOMS

The enclosed space in the centre of the officers' accommodation on the main deck is divided into two unequal parts. The smaller forward part, entered by a door from the larger room aft, is the dark room. It contains a sink with cold fresh- and salt-water taps, a lead-covered bench, racks for developing dishes, shelves and cupboards for the storage of chemicals and photographic plates, and other usual dark-room equipment. The dark-room lamp above the bench can be controlled either by a switch at its base or by another just inside the door. A Phillips X-ray viewing lantern is fixed to the bulkhead above the sink.

The larger room is used occasionally for photographic purposes and partly as a store-room. On the after port side is a bench carrying a sliding horizontal whole-plate camera

for photographing charts and illustrations. On the port side of the forward bulkhead is a sink with taps for hot and cold fresh water and salt water, and above it a large washing tank for X-ray negatives and large plates. In the starboard side of the forward bulkhead is the door to the dark room. Immediately abaft the dark-room door on the starboard side stands a tier of large chart drawers with a flush top, part of which is constructed to form a chart tracing table consisting of a heavy plate of glass which can be illuminated by a movable lamp from below. This space was formerly occupied by a half-plate camera, fixed vertically over a platform on which small organisms could be photographed with the aid of powerful spotlights.

Farther aft on the starboard side there are two high tiers of drawers used for storing spare stationery and apparatus. In the after port corner is a lift for passing stores to the biological laboratory above. It opens at the after end of the dividing bulkhead between the biological and hydrological laboratories.

Two book-shelves along the port side and one along part of the starboard side of the room are used for carrying a part of the scientific library.

The photographic equipment of the ship includes a Sanderson half-plate camera with which records of the work on board, of whaling activities, of natural life and of the places visited are made.

SCIENTIFIC INSTRUMENT STORE AND WORKSHOP

The small room between the carpenter's shop and the petty officers' bathroom, in the block of houses outside the port alleyway, is used as a scientific instrument store and as a workshop for the repair and overhaul of scientific gear. A bench runs along its outboard side with a port and a bracket light above. A small vice is attached to the bench and there are two tiers of drawers and open stowage space below the bench. All the available wall space is occupied with racks holding Nansen-Pettersen and Ekman water bottles, metre recording blocks, echo-sounding machine spares, current meters, release gears, Baillie sounding rods, harpoons and harpoon guns, sporting rifles and ammunition. On the deck against the bulkheads are racks for depth gauges and streamlined leads.

Of the two or three scientific assistants, each of whom ranks as a petty officer in the ship's complement, one is a man having electrical and general technical knowledge. His first duty is the care and operation of the echo-sounding machines (p. 102), but he has in addition the general care of scientific gear used on deck, with the exception of nets. The scientific storeroom is at the same time his workshop.

NET STORE

The long narrow room, which is the after compartment in the starboard block of deck houses, is used as a net store and workroom. Its position on the starboard side corresponds with that of the rough laboratory on the port side, and it is in a similar way near to the points from which nets are worked. The single door opens to the after deck. There are deep racks against the forward bulkhead for the accommodation of spare

1 m., 70 and 50 cm. nets bent on frames ready for use, and above these racks are bins for the storage of new nets. On the starboard side forward is a small bench with a port above, and aft of it are tiers of large bins for line, trawl twine, and general plankton net and trawling gear. On the port bulkheads are racks holding spares of small plankton buckets and strong fittings for the stowage of the heaviest release gears.

One member of the ship's company is rated as net man with the rank of a petty officer. The nets and the heavier scientific gear stored in the after hold, which is used entirely for scientific stores, are under his charge. He uses the net room both as a store and as a workroom for the assembling and repairing of nets.

SCIENTIFIC EQUIPMENT

The scientific equipment and methods used in the 'Discovery II' are in general similar to those described in vol. 1 of the *Discovery Reports*, but certain new departures have been made which should be described here.

DECK GEAR

The main winch, light deck machines and wire sounding gear are similar to those used in the 'Discovery' but with many detailed improvements resulting from experience. The positions of the machines, however, have in most cases been altered. The present arrangements are shown in Plate IV. It will be noted that the main winch (Plate XI, fig. 2) is now placed aft, a position which gives the best possible leads for the wire ropes and allows the winch man a clear view of the operations on the poop deck.

Two pedestal fairleads are installed abaft the main winch, one opposite the main and one opposite the auxiliary drum. Each has two Tyne metal sheaves running in roller bearings. Farther aft, on each side of the forward corners of the skylight to the petty officers' quarters, are two recording sheaves, $1\frac{1}{2}$ m. in circumference, mounted on steel pedestals (Plate XII, fig. 2). These sheaves are also of Tyne metal, running in special roller bearings, and operate dials recording in metres the length of warp paid out. There are two stern fairleads, one on each side of the poop (Plate XII, fig. 1), fitted with one large horizontal and two smaller vertical rollers. The warp from either drum of the main winch can be led to either fairlead, but in practice it has been found more convenient to use that on the port side.

A large floodlight is fitted to the top of the samson post to facilitate the working of nets from the poop at night, and the surface of the water aft is illuminated by a small light in the stern rail which is carefully recessed to prevent its being fouled by nets or trawls.

Davits, accumulators and recording dials of an entirely new type designed by Dr Kemp are used in conjunction with the deck machines (Figs. 3, 4; Plates X, XI). The davits for vertical plankton nets and water bottles consist each of a tubular steel post (15 ft. 6 in. high for the nets and Ekman type water bottles and 12 ft. for the Nansen-Pettersen water bottle) placed opposite the reel of wire. A horizontal derrick arm, 5 ft.

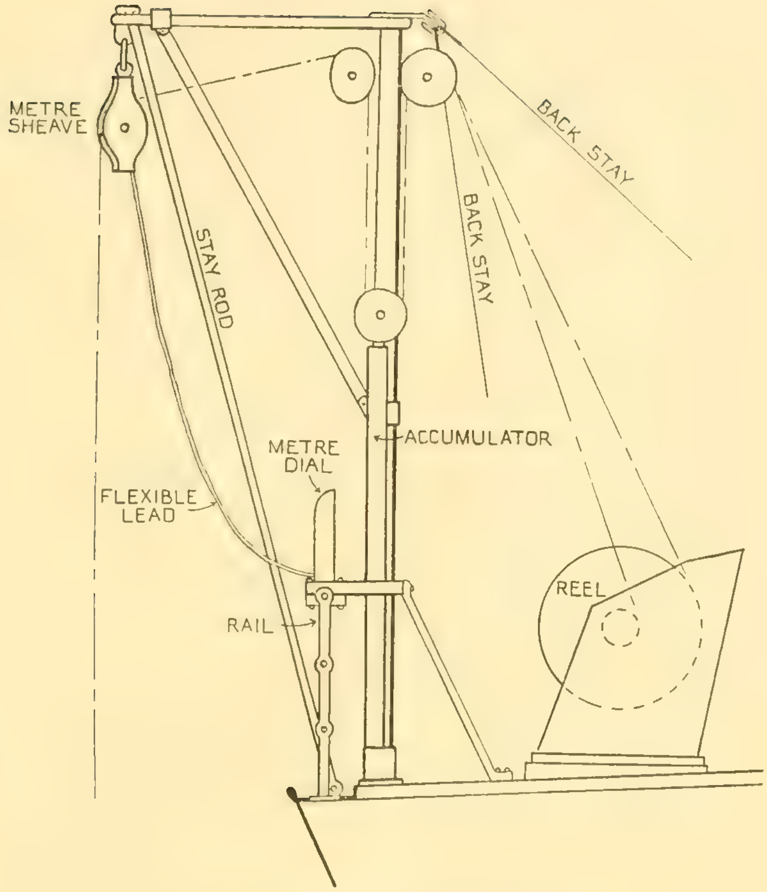


Fig. 3. Elevation of forecastle head davit.

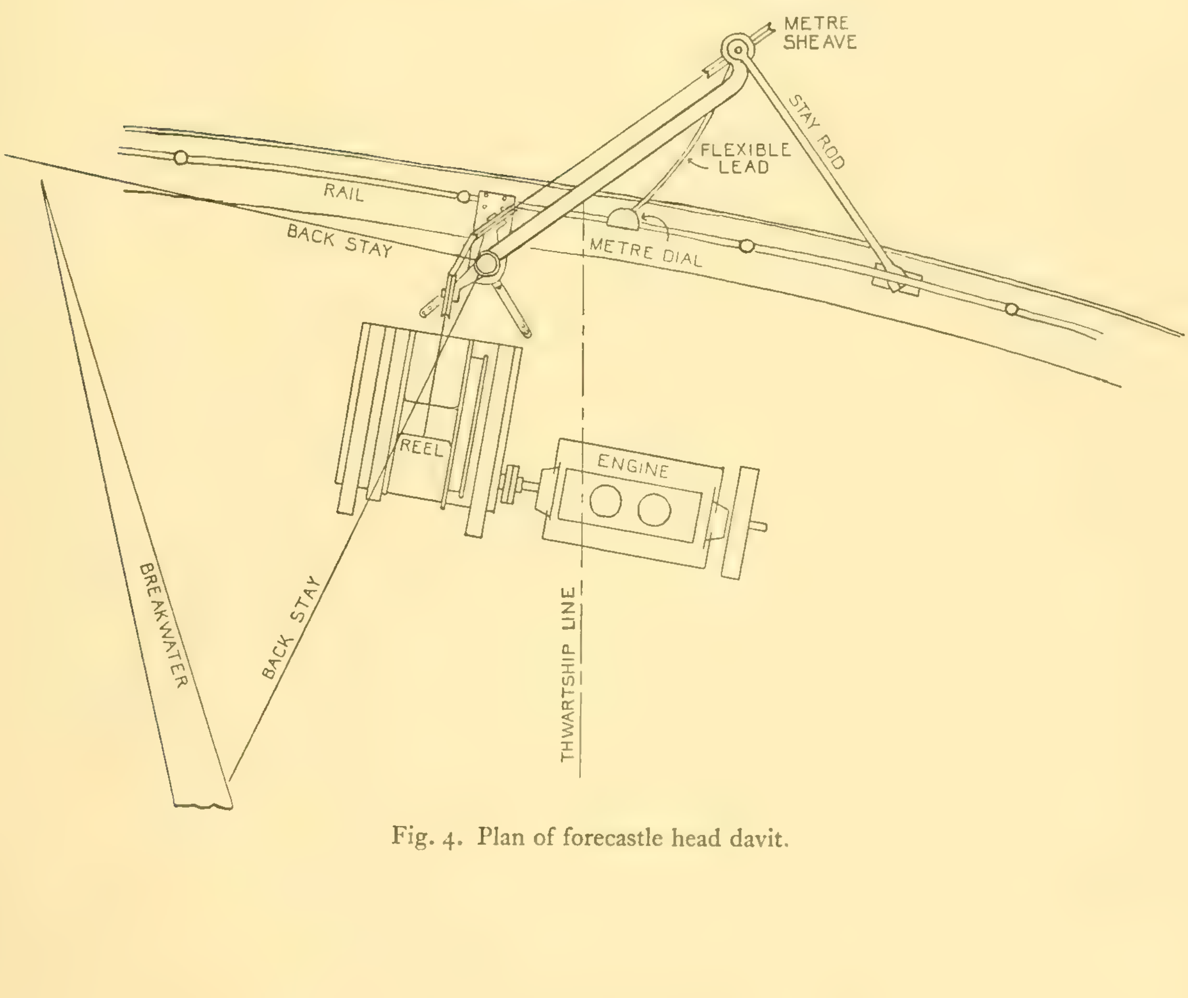


Fig. 4. Plan of forecastle head davit.

in length, with a metre sheave suspended at the end of it, projects from the top of the post, and when swung outboard is fixed securely at an angle of 45° from the rail by means of a light tubular steel stay which extends from a position on the deck or the rail to the outboard end of the derrick. An alternative deck position for this stay is provided, so that the davit can be turned inboard and secured in that position. The wire passes first to a sheave at the top of the post, thence down to another sheave attached to the head of an enclosed spring accumulator mounted alongside the post, up again over a third sheave also at the top of the post, thence to the metre sheave at the end of the arm and so down to the water. The metre sheave is connected by a flexible drive to a large dial counter, reading to 10,000 metres and fixed to the rail in a position facing the operator working the machine. The advantages of the new davits lie in the height of the horizontal arm above the water, which allows water bottles and nets to be hauled up to, or above, the level of the rail, in the ease with which the dial can be read and in the very efficient accumulator mechanism. The latter consists of a tubular casing to the top of which the sheave is attached. Inside it are compression springs and a rod. The rod is attached at its upper end to the top of the springs and at its lower end to the deck, so that tension on the wire causes the sheave and casing to move upwards against the springs. Slight tension, such as occurs when a net is being lowered, engages a light spring, but heavy tension, as when the net or instrument is being hauled up, brings a second and stronger spring into operation. The casing in which the springs work is watertight and is kept filled with oil.

In cold weather in the Antarctic the sheaves on the davits sometimes freeze in their bearings. To thaw them paraffin flares were formerly used (Plate X, fig. 1), but steam jets on flexible connexions have now been installed for this purpose.

APPARATUS

The water bottles, plankton nets, release gears, dredges and trawls are mostly similar to those described in vol. 1, pp. 181 *et seq.*; but both in apparatus and methods some innovations have been made.

The working of large closing nets has been notably improved by the use of a closing band operating on the inside instead of on the outside of the net. When a large net is closed in the ordinary way with an outside closing band and hauled towards the surface the resistance to the water is distributed asymmetrically, and the resulting surging of the net has been found to cause serious damage to the enclosed organisms. With 2-m. stramin nets the difficulty has been overcome in the following way (see Fig. 5). A closing band of 6-mm. wire is passed through rings on the inside of the net and fixed to the release gear. A stray line of similar wire doubled is attached at one end to the release gear and at the other end to the shackle at which the bridles meet. This stray line is of such a length that when the bridles are released the ring of the net falls back until the closing band has completely throttled the net. The stray line and bridles then, however, take up the weight of the ring and upper part of the net which maintain their

ordinary position square to the towing warp. There is then a symmetrical resistance to the water, and surging is avoided.

An appliance first used in the 'Discovery II' in 1933 is a phytoplankton net designed by Mr F. W. Harvey of Plymouth, who has already published a detailed account of it.[1] The net is quantitative, the volume of water which passes through it being measured by a vane and revolution indicator fixed near the mouth. Samples of phytoplankton are treated with acetone, and the amount of pigment extracted is measured by comparison with a series of colour standards. The net provides a swift and convenient method of comparing the relative abundance of phytoplankton in different localities, and is in daily use while the ship is at sea.

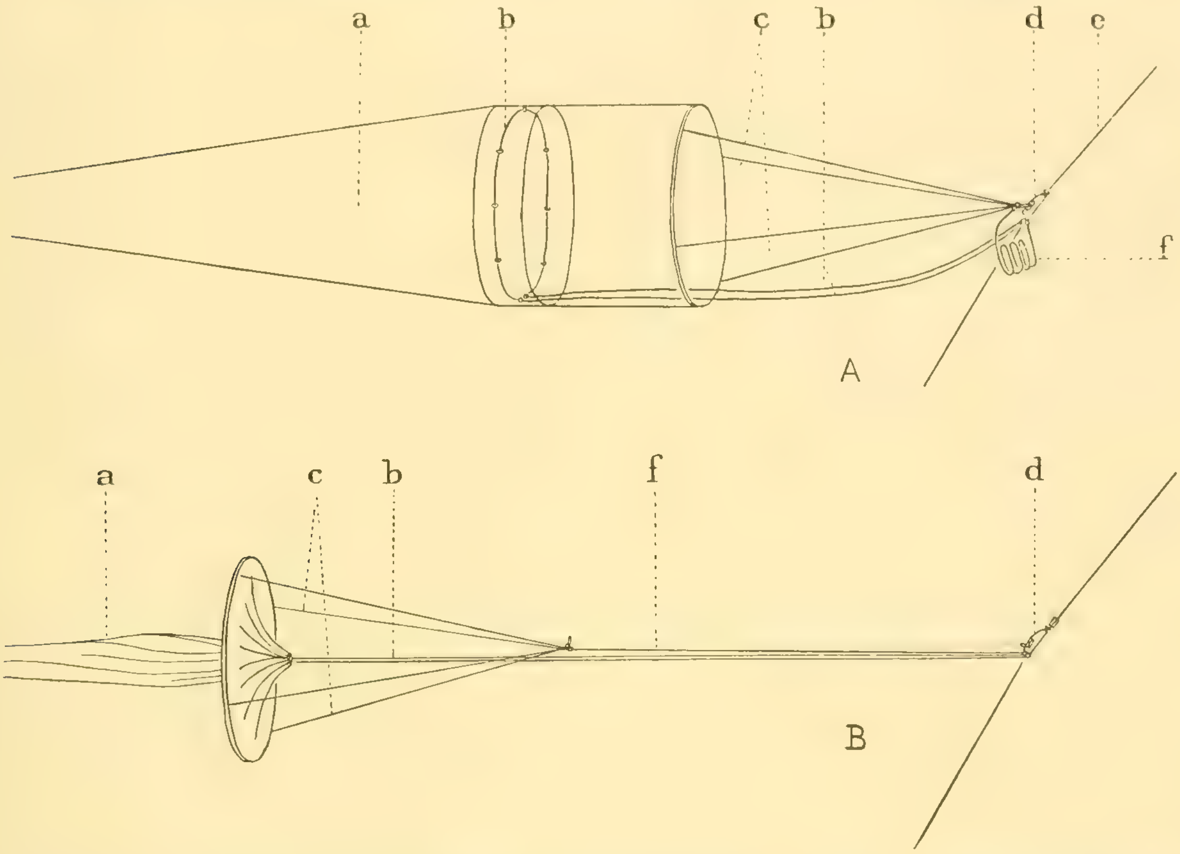


Fig. 5. Internal closing mechanism for large nets. A, open; B, closed. *a*, "fishing" part of net. *b*, throttling band. *c*, bridles. *d*, release gear. *e*, towing warp. *f*, stray line.

In the 'Discovery II' it has been found possible to take vertical hauls with the Young Fish Trawl (TYF), a stramin net with the fore part of large meshed netting to facilitate sinking. The net, mounted on a stream-lined frame 2 m. in diameter, was closed by an inside throttling line (as described above), and was used over the stern of the vessel, suspended from the long derrick boom attached to the samson post. A weight of 180 lb. was employed with this net. The release gear is of a special type with

[1] Harvey, F. W., Journ. Mar. Biol. Ass., n.s., XIX, p. 761 (1934); Journ. de Conseil, X, p. 179 (1935).

a striker of sufficient length to pass beyond the splice and swivel at the end of the warp. By means of snatchblocks the strain on the warp was partly taken up by a large accumulator spring which gave a very clear indication of the moment when closure was effected. With this apparatus vertical hauls have been taken successfully to a depth of 3000 m.; but the release gear often proved unreliable, especially in a sea-way. In the richly populated waters of the Antarctic this method is likely to prove of value, but in the warmer parts of the Atlantic the plankton is so scanty that adequate quantities cannot be taken in vertical hauls. The operation is in any case laborious and protracted.

A continuous plankton recorder is sometimes in use in the 'Discovery II'. It was designed by Professor A. C. Hardy and is an improved form of the model referred to in vol. I, p. 189. A description of it will appear in *Discovery Reports*, vol. XI (in press).

A new type of depth gauge (Plate XIII) is now used with deep horizontal or oblique townets. The mechanism is similar in principle to that of the Budenberg gauge, with a Bourdon tube working through a link motion which magnifies the movement and actuates a pen which traces the changes in depth on a circular card rotated by clockwork. This mechanism is mounted on a heavy steel base and is enclosed in a cylindrical steel cover which fits into a circular groove in the base. The groove is lined with a hard rubber washer. Experience with the Budenberg gauge showed that the leakage of water into the mechanism, which occurred at all depths over 400 m., was due to the method of securing the cover on the base. It was found impossible to get an equal strain on the twelve screw studs which hold the two halves together, and experiments showed that when the gauge was closed down omitting every other stud, there was, if anything, less leakage. In the new gauge the base and cover are mounted in a frame consisting of two vertical steel bolts joined by square steel bars. Through the upper bar is a large screw of fine thread which bears on the centre of the cover. Thus in place of the twelve studs used in the Budenberg gauge only a single screw is employed, and when this is tightened the cover descends evenly on the rubber washer and forms a watertight joint which in frequent tests has shown no sign of leakage even at a depth of 5000 m.

The apparatus and methods used in hydrological work are similar to those employed in the 'Discovery', though it may be mentioned that reversing and Nansen-Pettersen thermometers made by Messrs Negretti and Zambra, reversing water bottles by Messrs R. and W. Munro, Ltd., and Nansen-Pettersen water bottles by Messrs Elliot and Garrood of Beccles, have given entirely satisfactory results.

SOUNDING MACHINES[1]

Although the Lucas and Kelvin machines are retained in the 'Discovery II', sounding is now carried out almost exclusively with the echo-sounding machines. These are of the British Admiralty pattern and are supplied by Messrs Henry Hughes and Son, Ltd. They include firstly the oceanic pattern of Deep-Water Sounder with improved hammer of the balanced head type, an 'Acadia' Pattern Recorder, which can be used with the

[1] We are indebted to Mr H. F. P. Herdman for the information given in this section.

above hammer, a change-over switch from the oceanic machine being provided, and a Mark XII magneto-striction shallow-water sounder with curved scale recorder. The latter has been fitted recently in place of the old Pattern 751 British Admiralty shallow-water machine.

Soundings of great precision can be taken with the magneto-striction machine. It has a normal range of 0–230 fathoms, but by alteration of the motor speed it can be made to record from 0 to 230 feet over the same depth of scale. The oceanic machine and the 'Acadia' recorder also are more accurate at great depths than the Lucas machine.

The oceanic machine is in continual use, and soundings can be obtained from the greatest depths at all times when the weather permits. In rough weather the surge of water on the hull of the ship produces "water noises" which swamp the echo, but except in severe gales, when it is possible that the aeration of the surface water impedes the sound waves, a sounding can always be obtained if the ship is hove-to for a few minutes. The greatest depth so far measured with this machine in the 'Discovery II' is 7882 m.[1] As long as the ship is at sea routine soundings are taken at hourly or half-hourly intervals, and if rapid changes in depth are observed the intervals are reduced accordingly. The recorders are used mainly in coastal survey work, in shallow water or in any region where a clear delineation of the bottom contour is desired, as when the ship is passing over shoals, deep troughs or continental slopes; the demarcation of the Scotia Arc would have been quite impossible by ordinary sounding methods in the time at the disposal of the 'Discovery II'. The value of the recorder in uncharted coastal regions need hardly be emphasized.

Certain practical difficulties in the running of the machines have been encountered from time to time, but in the end all have been successfully overcome. The first and most serious difficulty met with was caused by the ship being mainly in water of which the temperature rarely exceeded 3° C. and was more usually at 0° C. or below. This caused the hot moist air from the compressor to condense on its sudden expansion in the deep-sea hammer, thus forming a sticky emulsion with the oil used to lubricate the piston. After quite short periods of running the piston used to jam and this necessitated the removal of the head from the hammer and the cleaning of both piston and cylinder, which at times was most inconvenient and caused serious delay. On the return of the ship to England in 1931 a steam coil was fitted round the hammer and this minimized the trouble considerably. In 1934, however, it was found necessary to fit a specially designed trap containing calcium chloride to dry the compressed air before it entered the transmitter. This made a considerable improvement, as it was then possible to get twelve to fourteen hours' continuous running in conjunction with the recorder.

The shallow-water hydrophone, which was enclosed in a small tank of water, was also seriously affected by the cold water, as the formation of ice in this tank forced the stalloy base of the microphone completely out of alignment. This difficulty was overcome by mixing glycerine with the water. The deep-water hydrophone, which is exposed to the sea, is not affected by the cold water.

[1] Herdman, H. F. P., *Report on soundings taken during the Discovery Investigations, etc.*

The old pattern of deep sea hammer with the unbalanced head was in use with the oceanic machine until 1935, and although requiring constant attention and adjustment, gave good results; but during the running survey of the South Shetland Group in 1934–5 it gave trouble continuously and was practically rebuilt on board. These repairs, however, were only of a temporary character and it was replaced by a new hammer of the balanced type during the refit in London in August 1935.

The 'Acadia' pattern recorder fitted in 1933 gives excellent results, the proved range during the third commission being from 20 to 2800 fathoms. Trouble, however, was experienced with the high tension batteries and the special paper. This paper is wetted by an endless wick dipped in a tank of water, and complete saturation is necessary as electrical contact must be made from the travelling pen through the paper to the tank face before the sounding can be recorded. The 'starving' of the paper may result from its uneven texture, or it may be caused by the wick becoming choked with fluff and chemicals which rub off the paper as it 'feeds' over the wick. To correct the latter fault the wick can be removed and boiled, but in the former case nothing can be done except to try a new roll of paper. This difficulty has been overcome in the Mark XII machine by using pre-saturated paper supplied in sealed containers and fed directly over a roller to the tank face instead of over a wick.

The battery trouble was more serious but was easily remedied. It was found almost impossible to maintain the H.T. batteries at a working voltage as they were seriously affected by the cold and damp. This was due to the door of the echo-cabinet, which is also an entrance to the chart house, being left open for long periods. As a correct H.T. voltage is absolutely necessary to produce a good record, and as it was impossible to have sufficient spare batteries, it was decided to replace them by accumulators. These were already in existence on board for the direction finding apparatus, and as the lead to the latter runs through the echo-cabinet, it was a simple matter to fit an extra switch and lead to the recorder. The charging board for these batteries is in the chart house, so there is no difficulty in keeping the battery charged to full capacity. When the Mark XII recorder was fitted in 1935, Messrs Hughes approved this machine being run from the same battery and a special switch has been fitted which allows either recorder or the direction finder to be used separately.

LABORATORY METHODS

Methods of sorting, preserving and storing specimens are similar to those described in vol. I, pp. 216–20, except that all the jars used are now of the Kilner pattern—with glass lid, rubber washer and copper ferrule. Two new sizes have been added: one is the wide-necked 7-lb. jar which is useful for large specimens and heavy catches of plankton, and the other is the $\frac{1}{2}$-lb. size used almost exclusively for plankton samples from the vertical 70 and 50 cm. nets. Formerly these samples were preserved in tubes, and there was some inconvenience in reducing the samples sufficiently to get them into the tubes. The catch can be poured straight into a $\frac{1}{2}$-lb. jar from the plankton bucket or settling

tube, and the standardization of the storage of vertical plankton samples is a further advantage. These jars are kept in wooden boxes containing two trays, each of sixty bottles, and as explained on p. 93, a cupboard in which the trays can be stored is provided in the biological laboratory.

Neutralized formalin and 75 per cent. alcohol are the preservatives most generally used.

In an earlier volume (vol. I, p. 219) we noted that paraformaldehyde was liable to form in the strong formalin used in the research ships, and that considerable quantities had thus been rendered useless. This difficulty, possibly though not certainly due to the low temperatures to which the formalin is exposed, has now been overcome with the assistance of Mr Arthur Ashworth, the manufacturer. He has supplied formalin with an increased alcohol content, and consequently with a reduced specific gravity, which has shown no tendency to polymerization when stored on board.

Distilled water for use in both laboratories and for photographic purposes is provided by a small steam-heated still of Brown's make which is fitted at the top of the engine room just inside the port door. The cooling of this still is by salt water, but the water distilled is from the ordinary fresh water supply.

Sund's slide rule is used for the direct determination of σ_t (density at the temperature of observation). This is an essential operation and the method is quicker and more accurate than the use of tables.

PLATES III—XIII

PLATE III

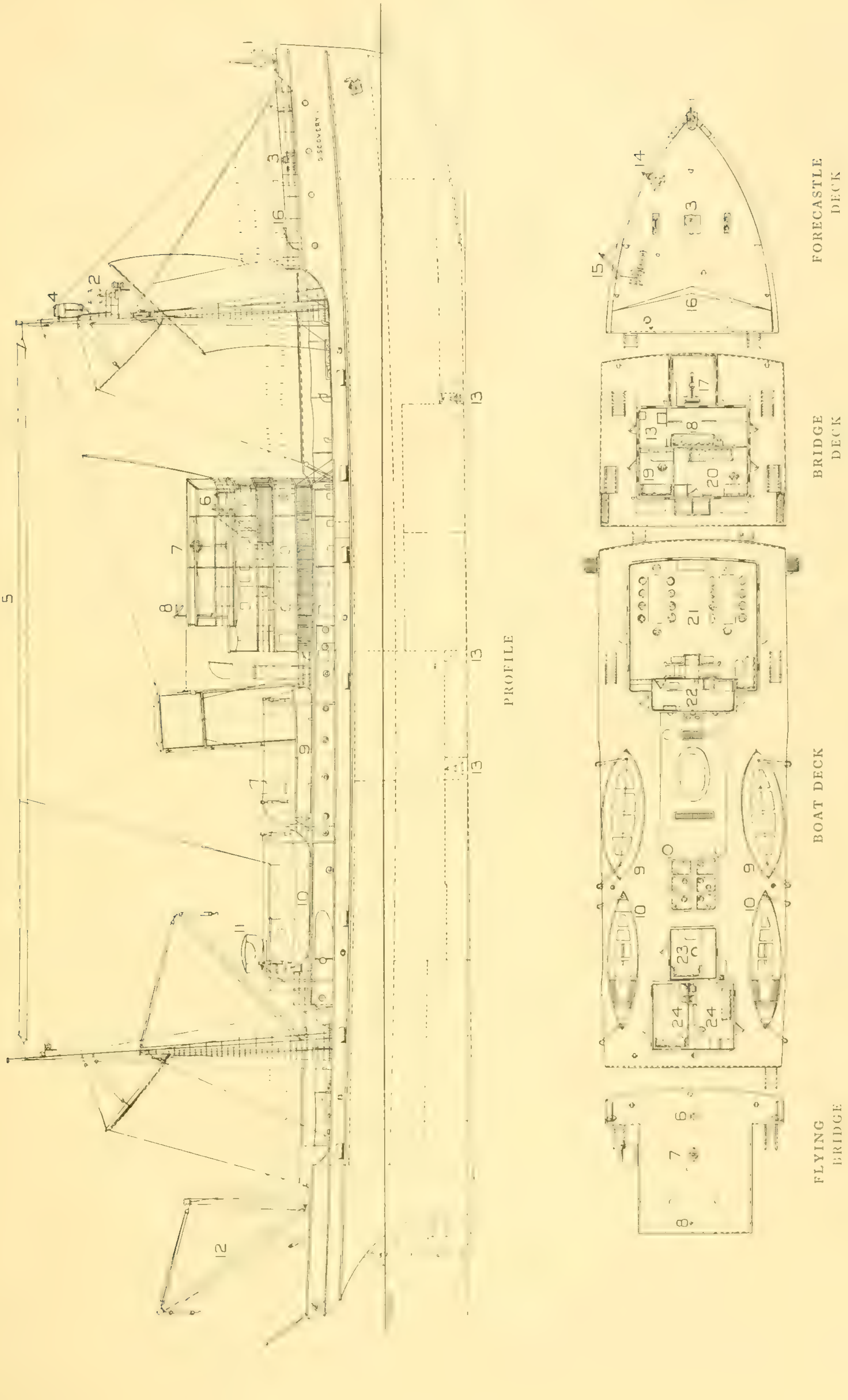
The Royal Research Ship 'Discovery II' at anchor
off Simon's Town, South Africa

THE ROYAL RESEARCH SHIP 'DISCOVERY II'

PLATE IV

Profile and plan of forecastle and bridge deck

1. Searchlight
2. Alternative position of searchlight
3. Capstan
4. Crow's nest
5. Wireless aerial
6. Standard compass
7. Direction finder
8. Semaphore
9. Lifeboat
10. Whaler
11. Motorboat
12. Samson post and derrick
13. Echo sounding apparatus
14. Lucas machine
15. Deep hydrographic machine and davit
16. Breakwater
17. Steering house shelter
18. Chart room
19. Survey office
20. Captain's cabin
21. Wardroom
22. Pantry
23. Wireless office
24. Sick bay

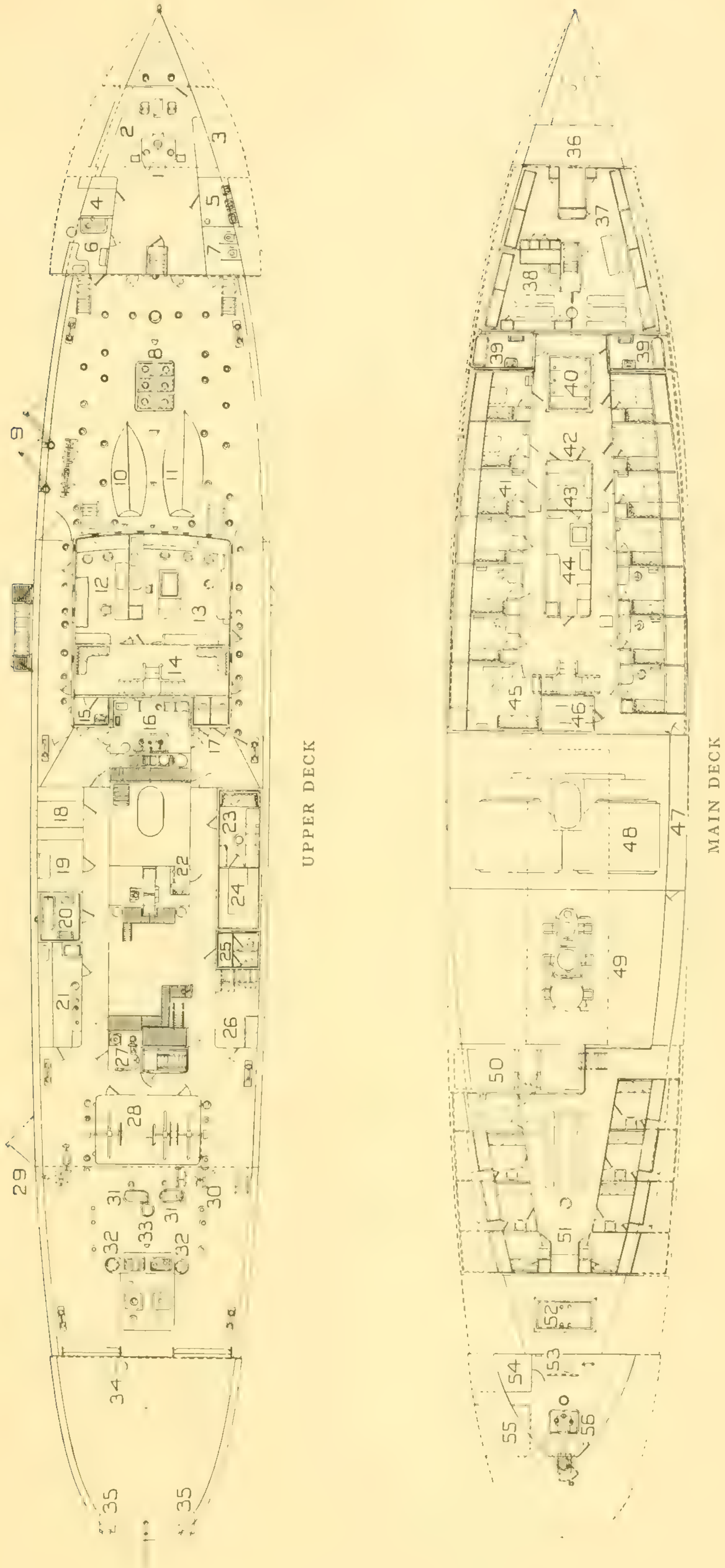


R.R.S. 'DISCOVERY II'

PLATE V

Plans of upper and main decks

1. Windlass
2. Carpenter's bench
3. Boatswain's store
4. Drying room
5. Crew's washhouse
6. Crew's galley
7. Crew's lavatories
8. Skylight to officers' accommodation
9. Shallow hydrological machines and davits
10. Pram
11. Dinghy
12. Hydrological laboratory
13. Biological laboratory
14. Lobby
15. Lavatory
16. Galley
17. Officers' lavatories
18. Workshop
19. Instrument room
20. Petty officers' bathroom
21. Rough laboratory
22. Fire-extinguishing apparatus
23. Office
24. Canteen store
25. Petty officers' lavatories
26. Net store
27. Refrigerating engine
28. Winch house and winch
29. Plankton machine and davit
30. Auxiliary winch drum
31. Pedestal fairleads
32. Recording fairleads
33. Skylight to petty officers' accommodation
34. Torpedo hatch to steering engine
35. Stern fairleads
36. Chain locker
37. Seamens' mess
38. Stokers' mess
39. Officers' bathrooms
40. Hatch to forehold
41. Officer's cabin
42. Linen locker
43. Dark room
44. Photographic room and library
45. Cabin of scientific officer in charge
46. Steward's store
47. Communicating alleyway
48. Boiler
49. Engine room
50. Refrigerating chamber
51. Petty officers' accommodation
52. Hatch to after hold
53. Hand steering wheel
54. Lamp room
55. Vegetable locker
56. Telemotor steering engine



R.R.S. 'DISCOVERY II'

PLATE VI

Fig. 1. R.R.S. 'Discovery II' in pack-ice, 69° 40′ S, 97° 04′ W.

Fig. 2. Frozen spray on fore deck and bridge.

Fig. 3. Well-deck davits encrusted with ice.

Fig. 4. R.R.S. 'Discovery II' in light pack-ice, south-west of the South Orkney Islands.

1

3

2

4

R.R.S. 'DISCOVERY II' IN THE ANTARCTIC

PLATE VII

Fig. 1. Wardroom.

Fig. 2. Officers' accommodation.

Fig. 3. Sick bay.

Fig. 4. Cabin of scientific officer in charge.

1

2

3

4

R.R.S. 'DISCOVERY II': ACCOMMODATION

PLATE VIII

Fig. 1. Biological laboratory, looking forward.

Fig. 2. Biological laboratory, looking aft.

1

2

R.R.S. 'DISCOVERY II': BIOLOGICAL LABORATORY

PLATE IX

Fig. 1. Hydrological laboratory, looking forward.

Fig. 2. Rough laboratory, looking forward.

1

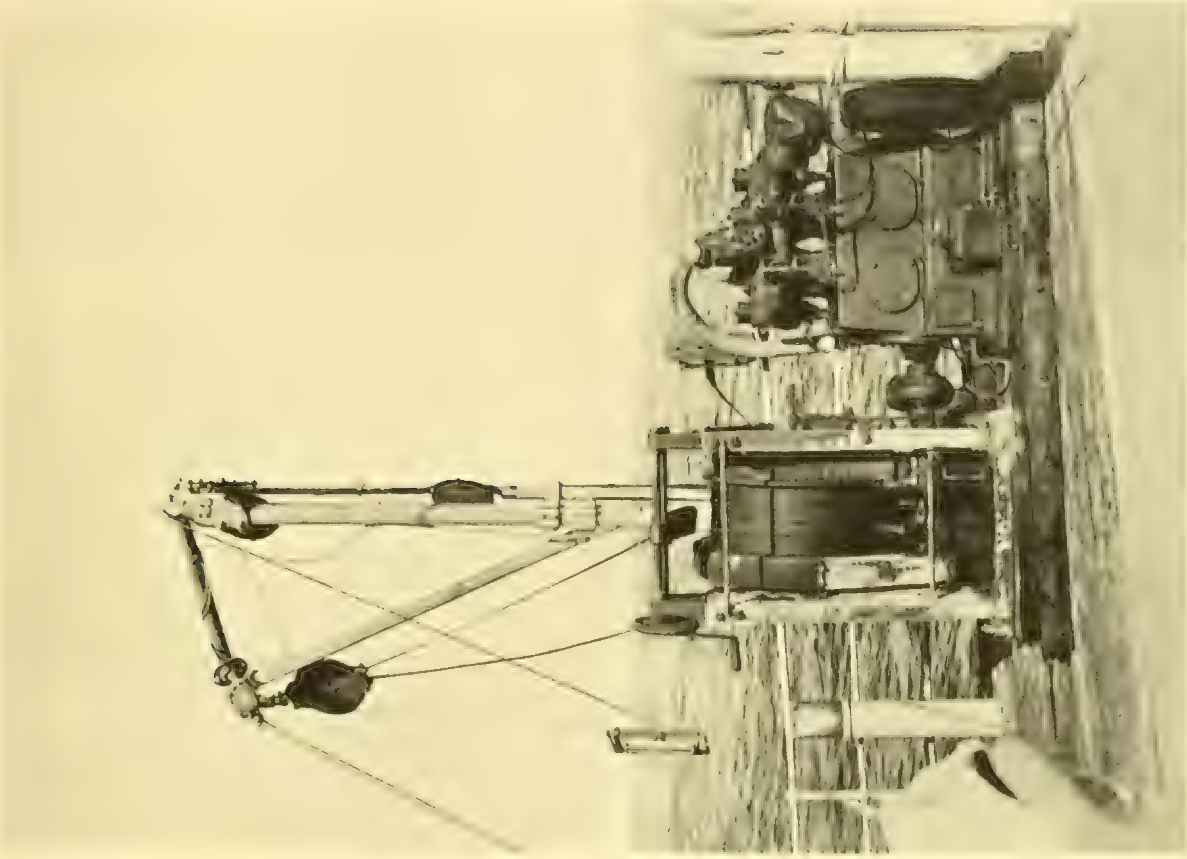
2

R.R.S. 'DISCOVERY II': LABORATORIES

PLATE X

Fig. 1. Well-deck machine and Nansen-Pettersen water bottle. Thawing sheaves in cold weather with paraffin flare.

Fig. 2. Forecastle head machine and Ekman reversing water bottle.



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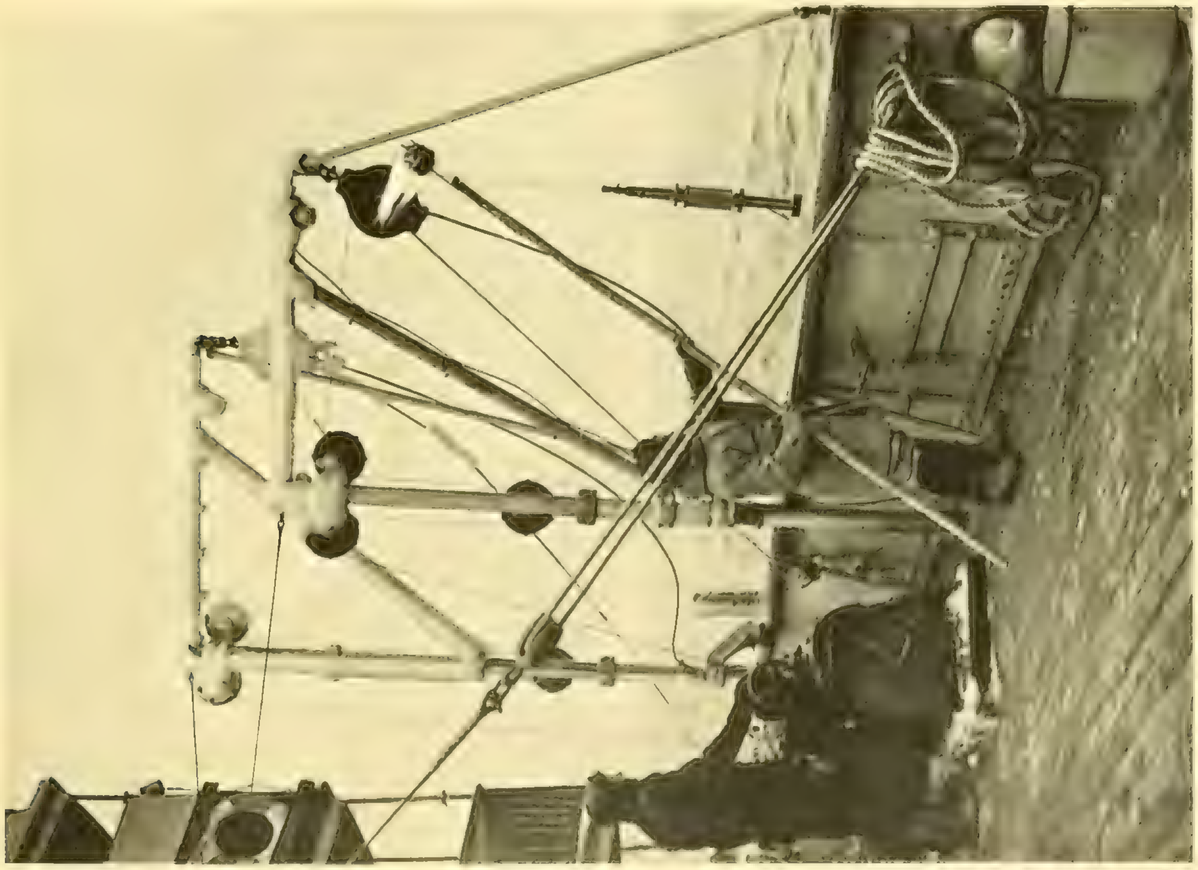


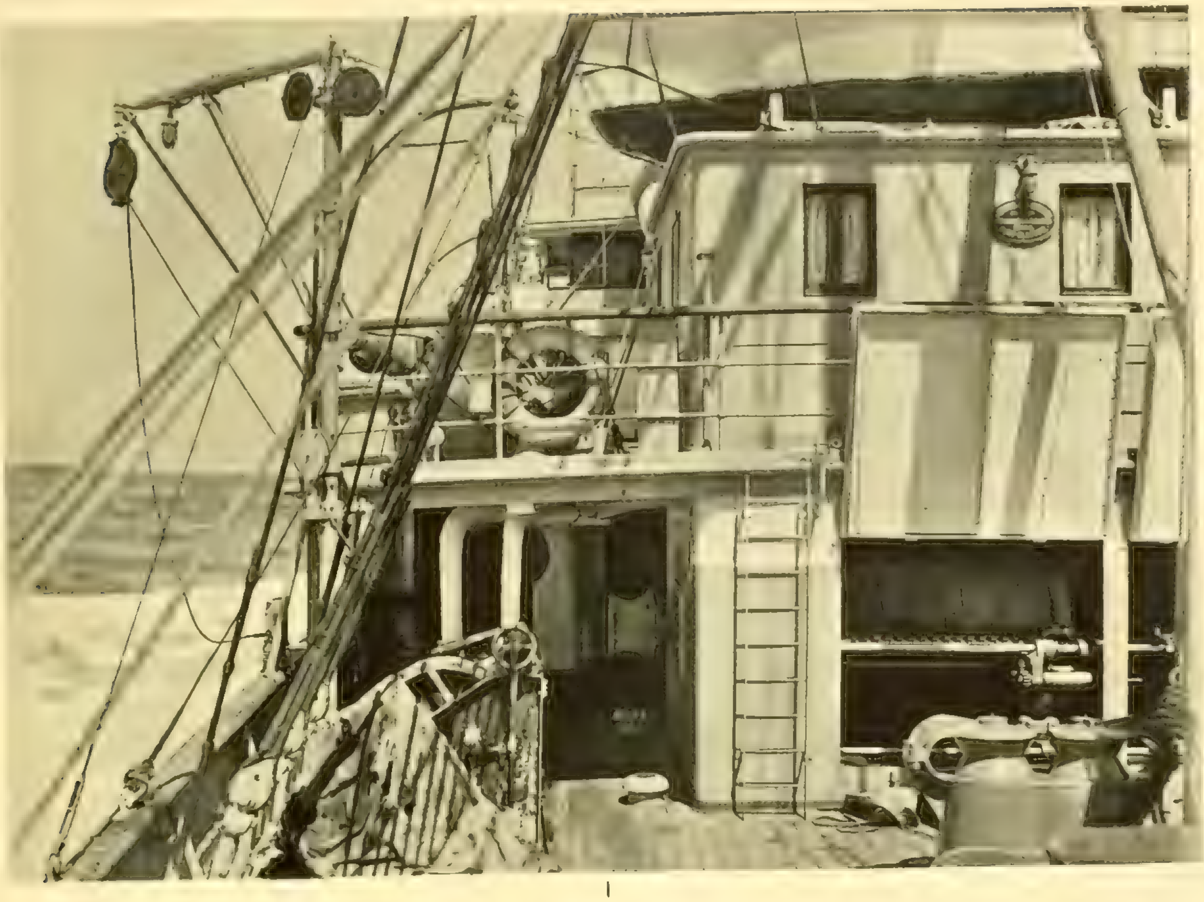
1

R.R.S 'DISCOVERY II': HYDROLOGICAL MACHINES

PLATE XI

Fig. 1. After well deck, showing plankton machine, winch house and bollards.

Fig. 2. Main winch, showing large and small reel, and traversing gear.



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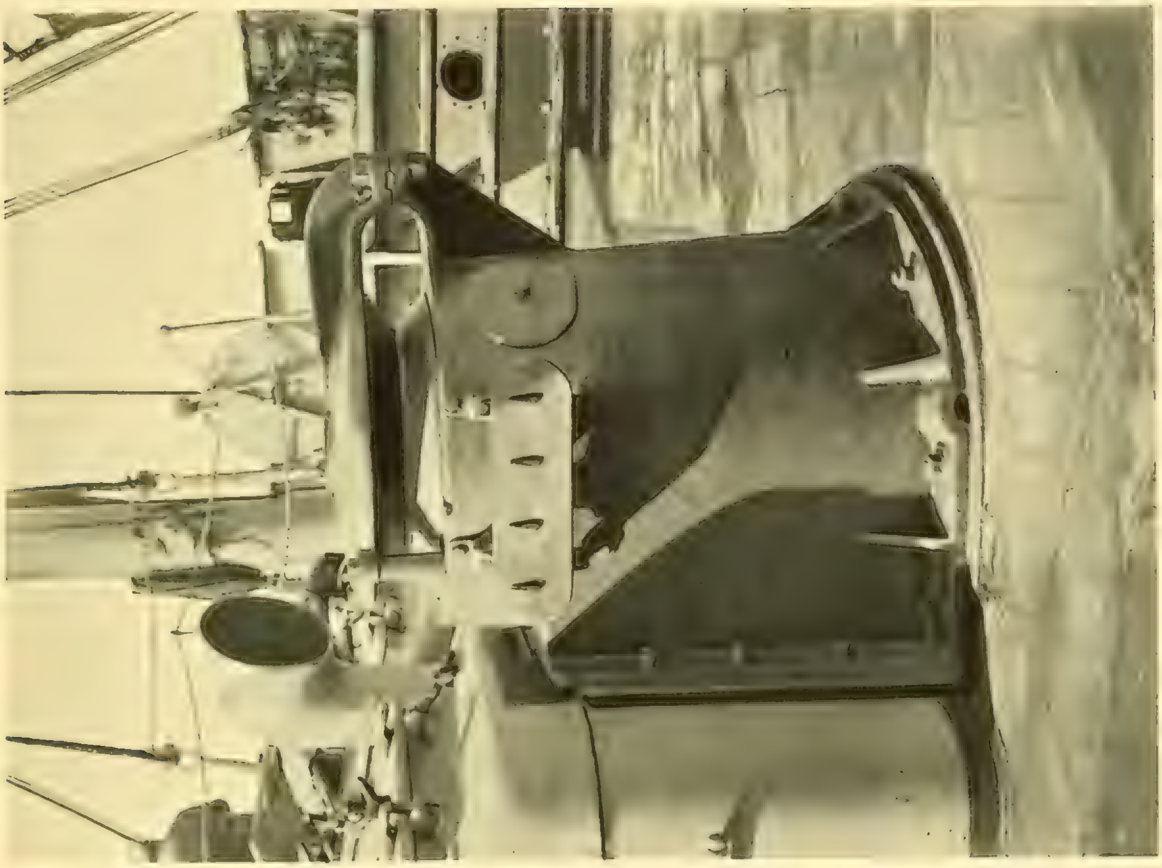
2

R.R.S. 'DISCOVERY II'. AFTER-DECK MACHINES

PLATE XII

Fig. 1. Poop deck, showing samson post and derrick, floodlights, fairlead, etc.

Fig. 2. Bollard and counter on after well deck.



2

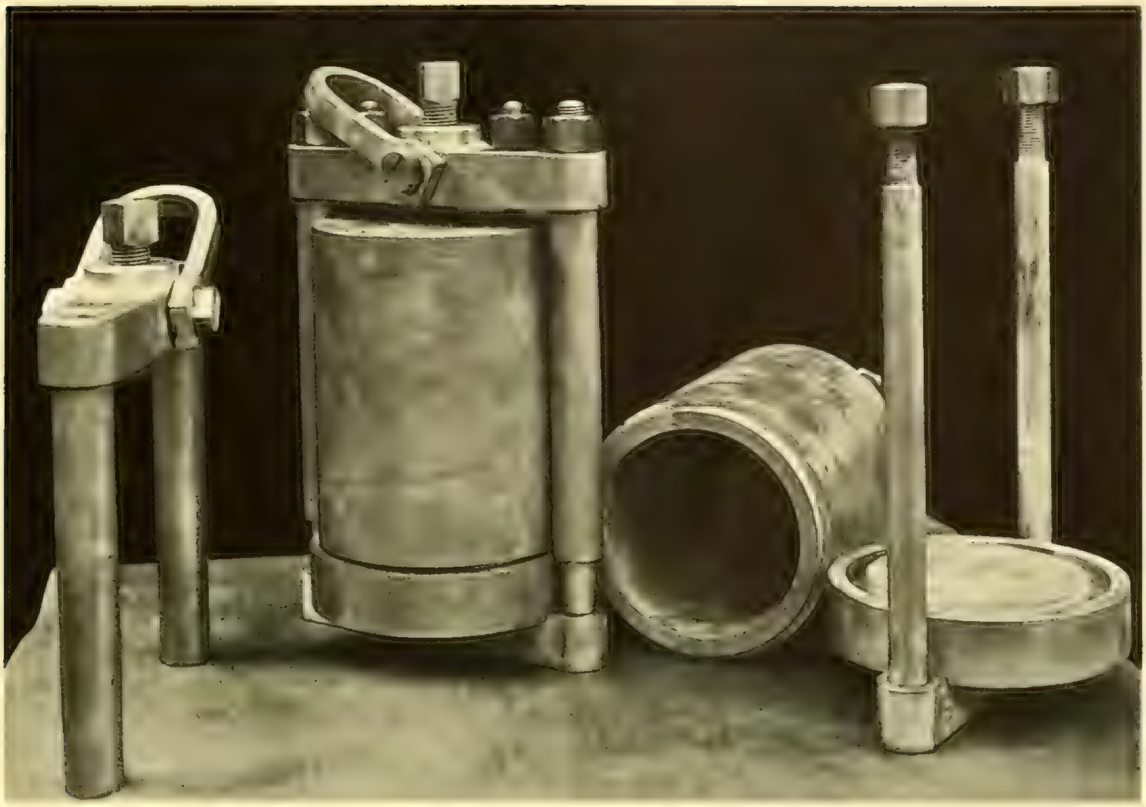
1

R.R.S. 'DISCOVERY II': AFTER-DECK FITTINGS

PLATE XIII

Fig. 1. Depth gauge casing, in parts and assembled.

Fig. 2. Mechanism of depth gauge. The clockwork mechanism is at the back of the depth chart.



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2

DEPTH GAUGE FOR PLANKTON NETS

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A REPORT ON OCEANOGRAPHICAL INVESTIGATIONS IN THE PERU COASTAL CURRENT

by

E. R. Gunther, M.A.

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A REPORT ON OCEANOGRAPHICAL INVESTIGATIONS IN THE PERU COASTAL CURRENT

By E. R. Gunther, M.A.

(Plates XIV–XVI; Text-figs. 1–71)

INTRODUCTION

The name Peru Coastal Current has been used to denote that part of the South Pacific anticyclonic circulation in which northerly current is most conspicuous; and whose physical, chemical and biological characteristics are most affected by admixture with water upwelled from the lower layers.

This report is the outcome of a survey carried out in 1931 by the R.R.S. 'William Scoresby'; it endeavours to bring together in a general description the salient features of the region as a whole, as they appear from a preliminary examination of the data, and to summarize the literature likely to be useful to those later engaged upon the preparation of more detailed reports.

The first two sections are introductory; the body of the report is mainly occupied with an analysis of facts; while hypotheses by which they may be explained are considered among the conclusions on the results obtained.

The Peru Coastal Current, sometimes called Humboldt's Current, represents a narrow belt of cold water which runs up the west coast of South America roughly from Valparaiso to the Gulf of Guayaquil, the boundary of Peru and Ecuador. The current varies in strength, ships having to reckon seriously with it at some times and in some places, whereas at others it is so weak as to be unnoticed. The waters are generally cooler than those of the adjoining Pacific and are often coloured green, khaki, brown, orange, and even red, by a wealth of marine life which gives rise in the south to a whaling industry and in the north to the richest bird population in the world and its commercially valuable deposits of guano (Plates XV and XVI). The interest of the current lies in the problems presented by its phenomena under normal and abnormal conditions and in their underlying causes, in its connection with the Chilean and Peruvian littoral, with the existence of saltpetre beds, and in its effects on the economic life of the inhabitants.

In his *Naturalist's Voyage round the World* Darwin (1845, p. 47) has summarized the features of the continent of South America in the following words:

> In the southern part of the continent, where the western gales, charged with moisture from the Pacific, prevail, every island on the broken west coast, from lat. 38° to the extreme point of Tierra del Fuego, is densely covered by impenetrable forest. On the eastern side of the Cordillera, over the same extent of latitude, where a blue sky and a fine climate prove that the atmosphere has been deprived of its moisture by passing over the mountains, the arid plains of Patagonia support a most scanty vegetation. In the more northern parts of the continent, within the limits of the constant south-eastern trade wind, the eastern side is ornamented by magnificent forests; whilst the western

coast, from lat. 4° S to lat. 32° S, may be described as a desert: on this western coast, northward of lat. 4° S, where the trade wind loses its regularity, and heavy torrents of rain fall periodically, the shores of the Pacific, so utterly desert in Peru, assume near Capo Blanco the character of luxuriance so celebrated at Guayaquil and Panama. Hence in the southern and northern parts of the continent, the forest and desert occupy reversed positions with regard to the Cordillera, and these positions are apparently determined by the direction of the prevalent winds.

These features are illustrated in Plate XIV. But for certain details of meteorology, as, for example, the implication that trade winds traverse the Cordillera, for which the reader is referred to pp. 124 and 195, the description is as apt on the centenary of his visit as on the day it was made. The Peru Coastal Current reaches its normal development off that arid strip of the west coast described by Darwin as falling between the luxuriant forests of Ecuador and the rank vegetation of the Patagonian Islands, that is between the parallels of 4° S lat. and 32–40° S lat.

Under abnormal conditions a reversal of the current brings hot equatorial water southwards along the coasts of Peru. This counter-current, usually known by the name *El Niño*,[1] is a seasonal occurrence of varying severity and happens usually in the months of January to March. With the hot counter-current come northerly wind and heavy rains which in some years work havoc on a coast that normally enjoys a dry climate and where the majority of buildings are of mud (*adobe*). In the sea the effects are equally disastrous. Fish and the lesser forms of life are killed by the sudden rise of temperature and drift on to the shore in enormous quantity. Widespread putrefaction ensues, and sulphuretted hydrogen emitted with other decomposition products blackens the paintwork of ships lying in harbour. This has come to be called the "Callao Painter", and locally by the name of *aguaje*. The loss of food is at once felt by the guano birds, which leave their rookeries. The young, deserted in their nests, are the first to perish, but adults also die or succumb to disease with great loss to the guano industry.

HISTORICAL

Many theories have been put forward to explain the presence of cool water on the Peruvian and Chilean coasts. Humboldt's classic hypothesis was published in 1811 after his visit to the west coast; but his were by no means the first of the observations about this interesting region.[2]

In 1543, within eleven years of Pizarro's conquest, Zarate was sent to Peru as Treasurer-General by order of the King of Spain, and his account of the country is recognized as one of the most authoritative of the early records. Accuracy on points of fact and recognition of essential problems make his geographical observations of great interest. They are contained in the following extract from Kerr's translation:

It may appear difficult to some of my readers to comprehend why no rain should fall in the plain of Peru, considering that the country is bounded along the whole of one side by the sea, where many

[1] Carrillo (1892) states that the counter-current is called "El Niño" (meaning "the child") by local fishermen because it is most noticeable after Christmas.

[2] The Royal Geographical Society has published an account of the earlier observations before and after Humboldt's time, and this forms an historical introduction to the present report.

vapours are constantly ascending, and on the other side by a vast range of mountain which is always enveloped in rain or snow. Those who have carefully considered this singular phenomenon, allege that it is occasioned by the continual prevalence of a strong south-west wind all along the coast and over the whole plain of Peru, which carries off all the vapours which rise from the sea and the land, without allowing them to rise sufficiently high in the air to gather and fall down again in rain. From the tops of the high mountains, these vapours are often seen far beneath on the plain in thick clouds, while all is quite clear and serene on the mountain. By the perpetual blowing of the same wind, the waters of the South-sea have a constant current along the coast to the northward. Others allege a different reason for this current; saying that the water of the South-sea having only a narrow outlet at the Straits of Magellan, which are only two leagues broad, and being there opposed by the Atlantic Ocean, they are forced to return to the northward along the coast of Chili and Peru. This constant wind and current render the navigation exceedingly difficult, from Panama to Peru for the greater part of the year; so that vessels are obliged always to tack to windward against wind and current.

The whole coast of Peru abounds in fish of various kinds, among which are great quantities of sea-calves or seals, of several species. Beyond the river of Tumbez there are no caymans or alligators, which is supposed to be owing to the too great coolness of the sea and rivers, as these animals delight in heat; but it is more probable that their absence from the rivers of Peru is occasioned by their great rapidity as they usually frequent rivers that are very still.

It is also written that the conquistadores in these harbours used to cool their drinks by hanging flasks over the side of the ship (Acosta, 1604).

The records of early navigators such as Drake and Hawkins also contain references to the current and to the climatic and physical features of the coast, but the hazards of life at sea when England was perennially at war with Spain must have effectually prevented any attempt at scientific observation; and although Hook had designed oceanographical instruments in 1662, they seem not to have been in use, in the southern hemisphere at any rate, before Cook's voyages. Richard Walter, writing of the west coast during Anson's voyage round the world in 1740, mentions specially his need of a thermometer. He begins his discourse upon temperature anomalies by stating that flying fish and bonito were not met south of lat. 8° S, whereas off the Brazilian coast they extend to much higher latitudes: this he ascribed to the low temperature of the water. After a philosophic review of many other temperature anomalies he correlates the cool water on the west coast with the height of the Andes: in the Gulf of Panama, where the Andes are relatively low, he points out that the water is warm, whereas off Peru, where they are high, the water is cool. He attributes the coolness of the Peruvian climate, then, to the snowfields on the Andes:[1] this and the formation of cloud has a refrigerating effect upon the water. He ends his discourse with the hope that

as it is a subject in which mankind, especially travellers of all sorts, are very much interested, that it were more thoroughly and accurately examined, and that all ships bound to the warmer climates would furnish themselves with thermometers of a known fabric, and would observe them daily, and register their observations; for considering the turn to philosophical subjects, which has obtained

[1] This view had gained currency before Walter's time. According to Kerr (1824, XI, pp. 32–33), Betagh writes: "One would expect the weather to be much hotter here; but there is no proportion between the heat of this part of America and the same latitudes in Africa. This is owing to two causes; that the neighbourhood of the snowy mountains diffuses a cool temperature of the air all round; and the constant humid vapours, which are so frequent that I often expected it to rain when I first went to Lima."

in Europe, for the last four score years, it is incredible how very rarely any thing of this kind hath been attended to.

Humboldt's observations of 1802 indicated that the water was cooler than the air and that the temperature rose rapidly with increasing distance from the shore. He thus showed that the water must cool the air and not *vice versa* as Walter had suggested, and in view of the northerly current and of the results obtained by Duperrey in 'La Coquille' he formulated the theory of a coastal current of Antarctic origin. Humboldt himself publishes little upon these conclusions, but Berghaus, who had access to Humboldt's manuscripts, expands his thesis and adds, as corroborative evidence, the observations made at other times of the year by Holmfeldt, Meyen and Duperrey.

At this time writers owed most of their knowledge to the French, who had equipped three expeditions to collect scientific data. 'La Coquille' in 1823 under the command of Duperrey, 'La Bonite' in 1836 and 'La Vénus' in 1837–8, constitute important attempts at collecting knowledge. In the published results of these and other works, most authors adhere to Humboldt's view and Arago in 1840 added that the current must have great depth (1780 m.), since if this cold water were to overlay warmer water its greater density would cause it to sink. The 'Beagle' visited the west coast in 1835, and although FitzRoy makes pertinent observations, neither he nor Darwin pays much attention to ocean temperature.

Bougainville (1837) is one of the earliest to level criticism at Humboldt's theory, pointing out that in 1825 the surface temperatures off Valparaiso were not much lower than those found at Lima by Humboldt. In 1844 de Tessan takes the matter further, arriving at the important conclusion that the low temperatures are the result of upwelling of the lower layers. In 1844 too, Maury considered application of the Law of Deviation to ocean currents, but this and upwelling do not seem to have been related to one another as cause and effect until the publication of Witte's paper in 1880. Dinklage in 1874 had nevertheless suggested that upwelling, together with a subsurface current of compensation towards the coast, might result by aspiration from the widespread westerly set caused by trade winds in the ocean at large.

Since the opening of the twentieth century the question of the Peru Current has been taken up afresh by writers with varying views. These are discussed on pp. 189–234, and it will suffice here to mention that as regards general principles the conclusions of Krümmel, Schott, Sverdrup, Vallaux and Schweigger will probably meet with general acceptance. Vallaux (1930) and Schott have examined the evidence critically. Schott's work—the first two parts of which were published in Germany in May 1931, the very month in which the 'William Scoresby' began her investigations—is the most complete account of the hydrology of this region that has yet appeared, and it has put all future workers in his debt. The greater part of the paper is devoted to a discussion of the intricate problems in the northern part of the area where the cooler Peru Current converges with warmer equatorial water. Our knowledge of this interesting region and of the Niño Counter-current is drawn almost entirely from his work and it is quoted frequently in the present report. For the more southerly parts of the

current, extending for a great distance along the South American coast, he gives fewer data: these and his conclusions are discussed on pp. 190–215.

Sverdrup (1930) and Schweigger (1931) published original observations collected respectively in the open ocean and close to the coast, and these represent the first attempt to collect hydrological data below the surface with modern instruments. Schweigger's observations were made in the upper 100 m. and include temperature, salinity, *p*H and the velocity of the current; but they lack serial arrangement. The work of the 'Carnegie' extended far into the ocean and traversed the eastern South Pacific in several directions. These observations are to some extent complementary to the work of the 'William Scoresby' and are therefore of particular value to us; it will be appropriate, before attention is drawn to them, to consider the nomenclature of the currents referred to in this report.

Writers up to 1837, including Humboldt himself, give no specific name to the currents on the west coast. Berghaus (1837, p. 572), therefore refers to it as "Der Strom kalten Wassers längs der West Küste von Südamerika, geschildert von A. von Humboldt", which on p. 584 becomes contracted to "peruanischen Strömung"; and only in a footnote does he suggest the alternative name "Humboldt's-Strömung". The more authoritative of later writers have used the geographical designation, though Humboldt's name came into vogue in the second half of the eighteenth century, mainly owing to the veneration in which it was beginning to be held. In a recent effort to revive this vogue, Wüst (1935) not only misquotes Berghaus and Sverdrup, but also appears to misconstrue their sense. His other arguments likewise reflect a partiality in his handling of the evidence and are thus hard to accept.

Uncertainty of the breadth of the current, and therefore of the region to which these names should be applied, has given rise to many expressions of opinion. In his *Physikal. Atlas* of 1839, Berghaus distinguishes a second current by the name of "Mentor's Gegen-Drift".[1] It lies to the westwards of the Peruvian Coastal Current of cold water, and flows partly towards the east; it is therefore oceanic and warm. Kerhallet (1856) followed Berghaus and Johnstone in making the distinction of the inshore and offshore currents, but interprets the "Mentor Current" differently, regarding it as having only northerly flow. Laughton (1870) suggested that the Mentor Current and the Peruvian Cold Current or Humboldt's Current were indistinguishable, and that in consequence retention of the name Mentor Current was not justified. This view implied enormous breadth in the Humboldt or Peru Current and that it was no longer to be regarded as a merely coastal current. In 1931 Sverdrup took the same view, calling it the Peruvian Current. Other writers, however, refer the names Humboldt Current and Peru Current to a relatively narrow zone.

In view of these widely different expressions of opinion it is necessary to reconsider the question of nomenclature in the light of conclusions reached in the present work.

The currents under discussion cover the area we recognize to-day as the eastern limb of the South Pacific anticyclonic gyratory movement. In the following pages it is

[1] Counter to the direction of the South Equatorial Current. The chart in question is dated 1837.

shown that the surface water close against the South American coast is hydrologically different from water which may also share northerly movement hundreds of miles out to sea, and consequently provides a distinct biological environment. There is, however, no sharp boundary between the two waters, the one merging gradually into the other. Moreover, from the dynamic standpoint it appears that the movement of both waters is actuated by similar principles, only in the one the presence of the coast induces upwelling and other modifications. In view of the emphatic differences in the character of the inshore and offshore components, it is desirable to draw a distinction between the two. The cool surface water close against the South American coast will be termed the Peru Coastal Current: and for contrast, the adjacent oceanic drift which, lying to the west of this, also seems to share northerly movement, the name Peru Oceanic Current is suggested. As, however, both currents compose the eastern limb of the anticyclonic circulation, and as no sharp boundary exists between them, they may jointly be referred to by the name Peru Current. Such definition of the Peru Current would not be inconsistent with the Peru Current of Schott and the Peruvian Current of Sverdrup.

The Peru Coastal Current has great variability, and counter-currents involving southerly and easterly drift have sometimes been reported within its boundaries: not, however, as a permanent feature, and with the exception of the Mentor Current of Berghaus and of *El Niño*, they have not been given names. Grounds are adduced in a subsequent section for believing that such counter-currents may form a permanent system of inshore and offshore eddies.

THE WORK OF THE 'CARNEGIE'

The cruises of the 'Carnegie', extending in many directions across the eastern South Pacific, form a valuable supplement to our own observations, which had of necessity to be near the coast. They cover the area westwards of the South American coast to the meridian of 115° W, and from the equator to the 40th parallel south, and give for the first time a modern account of the water layers at and below the surface from which it is possible to determine the bathymetric limits of the Peru Oceanic Current. Thus the 'Carnegie's' observations, though made in 1928–9, two years before those of the 'William Scoresby', give a picture of the general oceanic conditions without which a study of the coastal current by itself would lack perspective.

Sverdrup (1931) illustrates with salinity sections the relation between the Peru Current and the intermediate Antarctic current (Antarctic intermediate water), which he shows to be characteristic of the entire southern Pacific. The intermediate Antarctic current is shown to be a layer of low salinity at about 600–1000 m., which gains in depth and gains in salinity as it flows towards the north. The Peru Current, on the other hand, is shown to be a surface current whose depth does not exceed 300 m., and whose flow represents the eastern limb of an anticyclonic movement which is illustrated schematically by a figure taken from Johnstone (1923).

Sverdrup observes that three of the sections, from Sts. 40–45, 70–80, and 60–50, run

approximately at right angles to the Peruvian Current and may be termed cross-sections, while two, from Sts. 50–45 and from 60–70, are almost parallel to the current and may be called longitudinal sections. This observation may be considered open to question, for the sections above described seem to be orientated respectively at right angles and almost parallel to the intermediate Antarctic current, and not to the surface currents as figured schematically. In relation to the latter, the sections tend to encircle the centre of anticyclonic movement and in consequence to illustrate the surface current longitudinally in some parts and transversely in others. The significance of these salinity sections will therefore be better understood in relation to the Peru Current, when the surface currents and the trend of the surface circulation have been defined for the year in question: it will be possible then to decide the angle at which the several sections cut across the current.

The two sections which run more or less parallel to latitude show an increase of surface salinity when departing from the coast. In the more northerly of the two sections (Sts. 40–45), this is attributed to the presence of water from the Gulf of Panama (water of the Equatorial Counter-current), lying close to the Ecuador coast. The rate of increase is, however, very slow, which suggests that the section runs very much more with the current than across its path. Westwards of 90° W long., the section may be taken to represent the South Equatorial Current.

In the next section (Sts. 70–80) the low surface salinity inshore may indicate that the water has welled up from the lower layers near the coast of Peru. In this latitude the salinity increase on departure from the coast is such that the surface drift may also be inferred to have a marked westerly component, the concentration of surface salinity at greater distances from the coast being brought about presumably by evaporation of the surface layers. This section, which illustrates conditions in the Peru Current at much greater distances from land than any of our own, will be referred to in greater detail later (Fig. 1).

The other sections show an increase of surface salinity from south to north, but the increase is less rapid near the coast (Sts. 60–70) than further west (Sts. 60–50). Moreover, as noted above, the surface salinity is of a lower order near the coast than in the open sea. Sverdrup suggests that this is due to a constant transport of water of low salinity from the south, but, in view of the westerly set noted above, this impoverishment of surface salinity near the coast may be regarded as further evidence of upwelling.

In January and February 1929 when the 'Carnegie' ran her line westwards of Callao (Sts. 70–80, Fig. 1), she recorded an increase in surface salinity from just over 35 ‰ at St. 70, at 80 miles or so offshore, to more than 36 ‰ in 105° W long. The salinity of the intermediate Antarctic layer is about 34·5–34·6 ‰. At the western end of the section, that is west of 100° W long., a sharp salinity gradient separates the surface water from water below 250 m. This sharp gradient exists between the isohalines of 36·0 and 34·7 ‰ and constitutes a discontinuity layer. Above this layer the water seems to be tropical. At the eastern end of the section no discontinuity layer is present, the isohalines increasing gradually from the low value of 34·6 ‰ in the intermediate Antarctic layer

to 35·0 $^{\circ}/_{\circ\circ}$ at the surface: an increase of only 0·4 $^{\circ}/_{\circ\circ}$ in 500 m. This may be attributed to upwelling, but the trend of isohalines between Sts. 70 and 71 should be interpreted with caution, since conditions in the surface stratum may have altered considerably in the three weeks which intervened between the working of these two stations (Fleming, 1930). Likewise the surface change from 35 $^{\circ}/_{\circ\circ}$ inshore to 36·0 $^{\circ}/_{\circ\circ}$ in the west takes place gradually. From this section it is impossible to say where the influence of upwelled water is no longer felt and so to ascribe positive limits to the Peru Coastal Current.

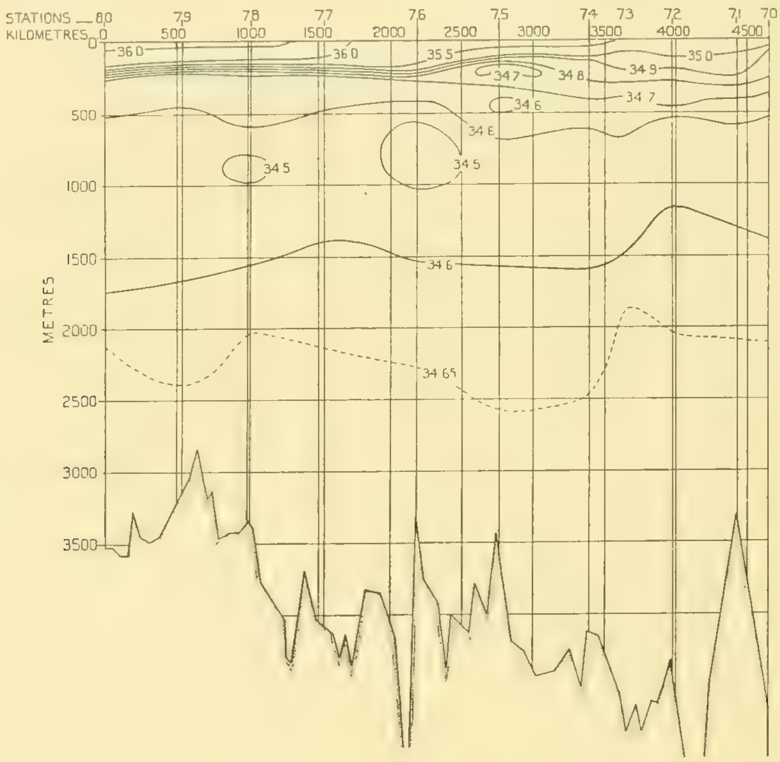

Fig. 1. Salinity section of the eastern South Pacific based on 'Carnegie' Sts. 70–80. The section runs westwards of Callao. (After Sverdrup.)

The other lines run by the 'Carnegie' and figured by Sverdrup furnish no better evidence on this point, but suggest that the influence of coastal upwelling is felt less and less as distance from the coast increases, that it has no abrupt end, and is felt at greater distances from the shore in low latitudes (off Peru) than in high latitudes (off Chile). Thus in lat. 25° S, the data figured by Sverdrup in figs. 6 and 8 give grounds for supposing that the influence of upwelling might be felt as far as 600–700 miles offshore: the isotherm of 15° C. for example, being found nowhere as deep within this distance as it is at some 680 miles from the coast. In 15° S the influence of upwelled water may be felt at 1200–1500 miles, and at 5° S, where water is travelling westwards, its influence may be carried indefinitely.

THE WORK OF THE 'WILLIAM SCORESBY'

The 'Carnegie's' work lay too far from the shores of Chile and Peru to shed much light upon the vexed questions of the Coastal Current. The phenomena of major interest, and those around which most discussion has centred, are to be found on the tracks of coasting steamers and on the grounds frequented by fishermen. Examination of the surface stratum and of the lower layers, not only in this zone, but as far into the ocean as circumstances would permit, was the main purpose of the present survey. The present report, essentially preliminary, is based on the observations made by the author and his colleagues on board the R.R.S. 'William Scoresby', and is confined to an account of conditions in the upper layers.

In 1931 a scheme of investigation was prepared by the Discovery Committee with the assistance of the Hydrographic Department of the Admiralty. Owing, however, to our limited knowledge of the hydrological conditions on the coast, the programme was kept flexible, and execution of the work was to a large extent guided by the results obtained as we went along. Thermometer records were plotted on blank charts hour by hour as collected, and the position of stations and the ship's course were adjusted as the work developed. Thus we gained a bird's eye view of the general conditions as we worked up the coast. This report is concerned with the layers between 400 m. and the surface with especial reference to their temperature and salinity, to the effect of wind upon water movement, and to the consequent effect on the phosphate content of the surface and on the life in the sea.

ACKNOWLEDGMENTS

The analysis of water samples for their phosphate content was carried out by my colleague Mr A. H. Laurie, and the results as plotted by him are illustrated in Figs. 40 and 54–61. All the samples were examined within 3–4 days of collection and many within a few hours while still at sea. The consistency of the major differences in the phosphate distribution suggests that they are significant but the conditions of work make a considerable, but undetermined, error probable. Mr G. W. Rayner, who joined the ship towards the latter end of the survey, contributed to the work and has made a preliminary examination of the phytoplankton collections (pp. 178–181). The track of the ship, illustrated in Figs. 5–13, 70 and 71, was drawn by Mr F. E. C. Davies, who performed the duties of navigating officer and was in command of the ship during her work off Peru. The meteorological data are extracted from the deck log book, where they were entered by the officers of the watch. In making acknowledgment of the work of colleagues our thanks are also due to Lieut. Rafael Torrico of the Peruvian Navy, who was seconded to the ship as liaison officer and who contributed very greatly to the success of our operations.

It has been our good fortune to have the help of Mr D. J. Matthews of the Hydrographic Department of the Admiralty, who assisted both in planning the research and

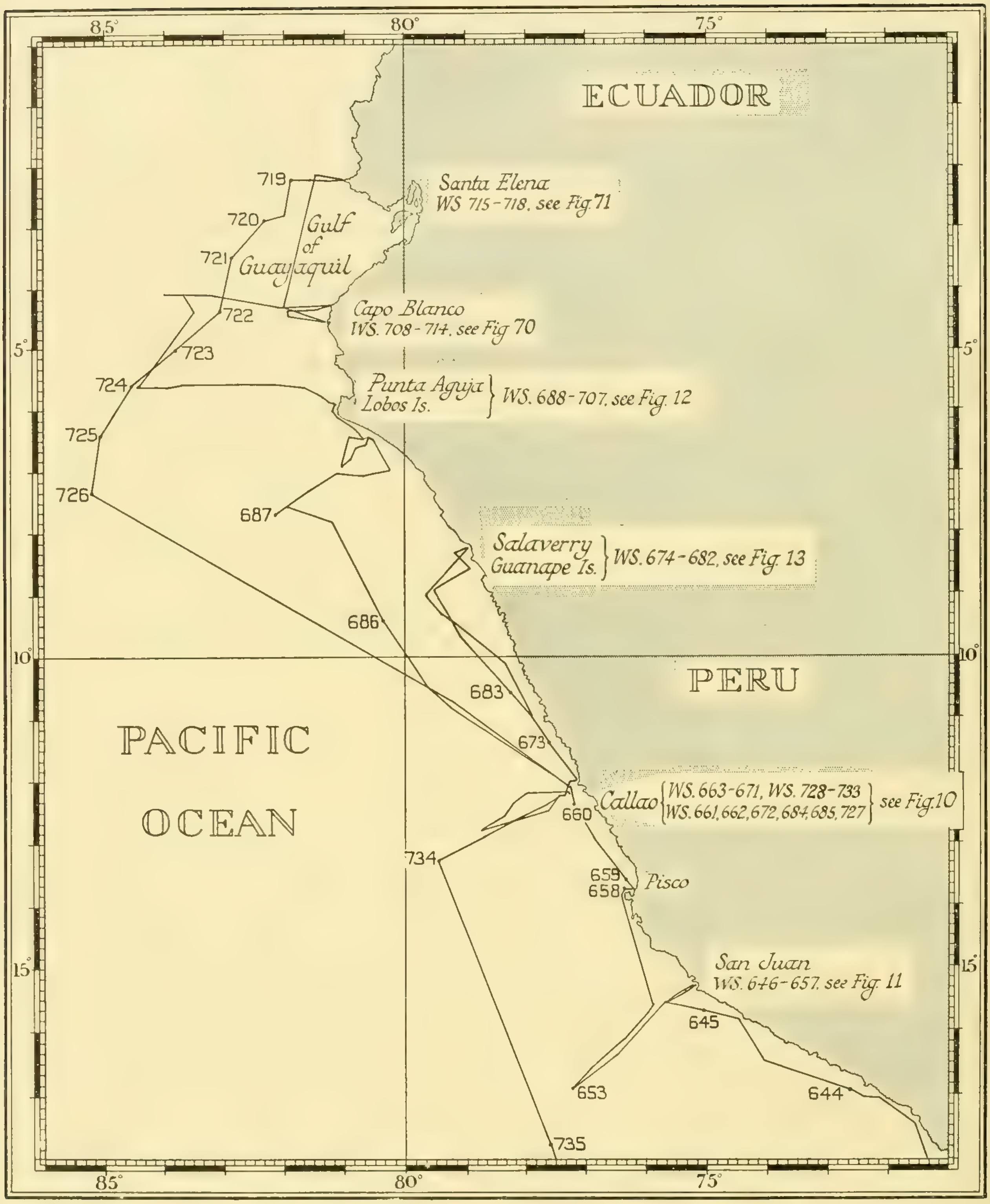

Fig. 2. Track chart of R.R.S. 'William Scoresby', June to August 1931. Reference to Figures in which the ship's movement is shown in detail is made opposite each line of stations.

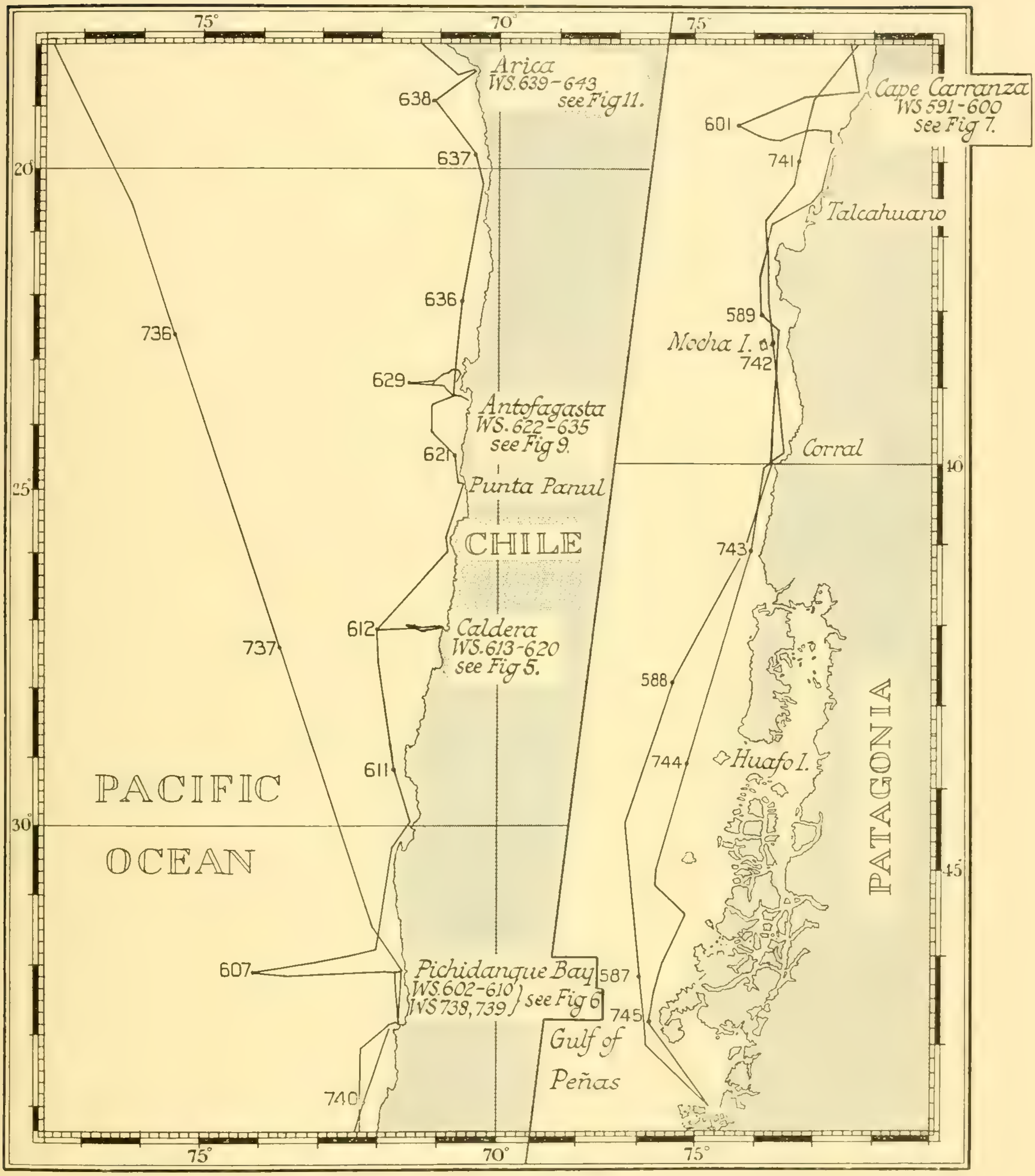

Fig. 3. Track chart of R.R.S. 'William Scoresby', May to June and August to September 1931. Reference to Figures in which the ship's movement is shown in detail is made opposite each line of stations.

in his continued interest in the progress of the work; to him we owe a translation of Schott's recent writings. I am indebted to Miss D. M. E. Wilson for titrating the water samples and to Miss E. C. Humphreys for the care she has taken in preparing the figures for reproduction. Among the many others who have helped I wish to thank especially Dr C. E. P. Brooks and Dr J. A. Fleming, Mr E. W. Barlow, Mr G. E. R. Deacon, Dr T. J. Hart, Mr G. R. Crone, and Miss E. I. Holme. In particular, I am indebted to Dr S. W. Kemp, whose help and sympathy have greatly facilitated the execution of the work.

The Carnegie Institution of Washington has kindly supplied manuscript data of the 'Carnegie's' cruises in the Pacific; the Admiralty and the Royal Geographical Society have extended library facilities, and the Meteorological Office has loaned daily weather bulletins of Chilean Meteorological Stations.

EQUIPMENT AND METHODS

Winter months were allotted to the survey because the R.R.S. 'William Scoresby' was due to work in the south during the southern summer; there was otherwise no special design in choice of season, though it was hoped that by compressing the work into a relatively short space of time symmetrically arranged about the winter solstice uniformity in weather conditions and temperature might be secured.

The ship at first under the executive command of Lt.-Comdr. J. C. C. Irving, R.N. (Retd), and later of Mr F. E. C. Davies, cruised over the whole area from the Gulf of Peñas to Santa Elena in Ecuador. On the northward journey from May 18 to July 26 she carried out the greater part of her programme, working eleven lines of stations across the path of the current in the space of two months (Figs. 2 and 3). The return journey southward was made the occasion for an additional line off Santa Elena and for working oceanic stations in a meridional direction and for repeating the observations made off Callao in July. The ship steamed on a direct course from the Callao line to Pichidanque Bay.

Two objects were kept in view in planning the positions of stations: firstly the securing of a sufficient number of observations to provide data for hydrological sections, and secondly to span the breadth of the current. The first station of each line was placed as close as possible to the shore. Owing to isothermal irregularity the stations over shallow water were placed close together, but those following, over deep water, had to be placed at progressively greater intervals. Each line was terminated when the isotherms beneath the surface showed a horizontal tendency. This point on the line, dictated by considerations of economy, might or might not approximate to the western boundary of the Peru Coastal Current, but it always lies between the cooler inshore waters, where upwelling and coastal influences cause isothermal irregularity, and the open ocean, where the surface water is warmer and where the temperature shows a condition of comparative stability.

When running from one station to another on the same line, the ship was usually

steered in a direction normal to the coast; but she was allowed to drift off this course according to the strength of wind and current in a direction parallel to the coast. The differences between the observed and the dead reckoning positions of the stations are consequently a measure of this drift: and the track chart is therefore a graphic representation of the combined effects of wind, tide and current upon the ship's course. By this method their combined force is more easily assessed than it would have been had an attempt been made to place the stations on a straight line.

At each station, where depth allowed, observations were made at the following depths: surface, 10, 20, 30, 40, 50, 60, 80, 100, 150, 200, 300, 400, 600, 800, 1000, 1500, 2000, 2500 and so on at 500 m. intervals to the bottom. When running outward from the shore into deep water, soundings were made at alternate stations: on this series of stations hydrological observations were made all the way to the bottom; on the alternative series, the hydrological observations were made no deeper than the depth of the preceding sounding.

The work included determinations of temperature, salinity, phosphate and oxygen, and nets of different mesh were fished vertically from 100 to 0 m. and obliquely from 250 to 100 m. and 100 to 0 m. to sample the plant and animal constituents of the plankton. A complete schedule of these observations will be published in due course as a Station List in the present series. When the ship was under steam from one station to another a routine of four-hourly observations of surface temperature and salinity was performed; but additional surface temperatures were taken as occasion demanded, and here the want of a continuous thermograph was acutely felt. Phosphate was estimated by Denigès' coeruleomolybdic method as modified by Atkins (1923).

The equipment used on this survey was essentially similar to that described by Kemp and Hardy (1929). Water samples from depths not exceeding 400 m. were collected with the Nansen-Pettersson insulating water bottle, while at greater depths the Ekman reversing water bottle was used.

Throughout this report, figures referring to the same locality are printed as far as possible on comparable pages. As far as possible they have also been reduced to a common scale. Thus track charts are not only comparable with one another, but their scale has been adjusted to fit the scale in miles of the various sections of temperature, salinity and phosphate, and of the curves illustrated in Figs. 29 and 30. Exceptions are furnished by Figs. 2, 3, 28, 35, 42 and 51.

WIND

Records of wind, based on personal estimates of its direction and force, were kept every four hours by the officers of the watch; and in addition we have had access to daily weather bulletins issued by the Chilean Meteorological Office. The data may conveniently be considered under three heads: observations on board ship at a distance of more than 50 miles from land; observations within 50 miles of land; and those of Chilean coastal stations. The former two are plotted in Fig. 4 separately as residuals

of observations between every two degrees of latitude: the last separately for each station as the residual of the observations available for a fortnight prior to our arrival off the coastal strip in question.

Reduction of wind forces to residuals followed the normal practice of vector averaging: the directional velocities expressed as miles per hour were first resolved along the cardinal points of the compass; these were summed and reconverted into an aggregate resultant which was then divided by the original number of observations.

This method of reducing data gives a working idea of wind conditions, even though the number of observations represented by each arrow in Fig. 4 may vary according to the length of time spent by the ship off each stretch of coast. In certain instances, when a rapid change in wind was followed within a few hours by changes in hydrological conditions, the data before and after the change have been plotted separately. This has been done off Antofagasta and off northern Peru where the ship covered the same ground two or three times, and the data on the voyage northward in May to July have been plotted independently of the voyage southward in August to September.

Specific instances of the effect of wind upon the ship's drift and upon upwelling are discussed later; here it may be well to take a general view of the winds prevailing on the west coast at the time of our visit.

Fig. 4 will show the existence of natural regions in each of which the majority of winds usually blow in a set direction. We may differentiate between the following: south of lat. 38° S winds are irregular in force and direction in the months of both May and September. This region lies in the circumpolar tract of the "westerlies", known also as the "roaring forties". North of 38° S winds are more regular. They appear to have least force over land and most far out to sea. The weakest winds over the coast are naturally least certain in direction, but those immediately offshore blow almost without exception parallel to the coast, i.e. they are southerly winds off Chile and south-easterly off Peru.

Farther from the Chilean coast, in August at any rate, the winds showed a departure from the coast-line direction: they veered from southerly inshore to south-easterly as the distance from land increased. These winds between the parallels of 32 and 4° S lie in the path of the south-east trades, and it would appear that while the south-east winds off Peru and far out to sea off Chile may be classed as normal trades, the coastal winds represent a departure from them. Such a distribution of winds is normal for the circulation in the eastern South Pacific; Brooks (1929) thus summarizes the position as it is understood at the present day:

> The centre of the South Pacific anticyclone lies off the coast in the latitude of 30° S, and pressure is highest in this latitude, decreasing slowly northward and more rapidly southward. The northern part of the region as far as 30° S is throughout the year under the influence of the south-east trade winds, which cross the equator and blow into the Gulf of Panama as south-westerly winds. South of 30° the winds are south-westerly, rapidly becoming westerly and increasing greatly in force as the "roaring forties" are approached....
>
> From the belt of high pressure in about 30° S pressure decreases steadily southward, very rapidly between about 40° and 50°. Here strong westerly winds prevail throughout the year, often of gale

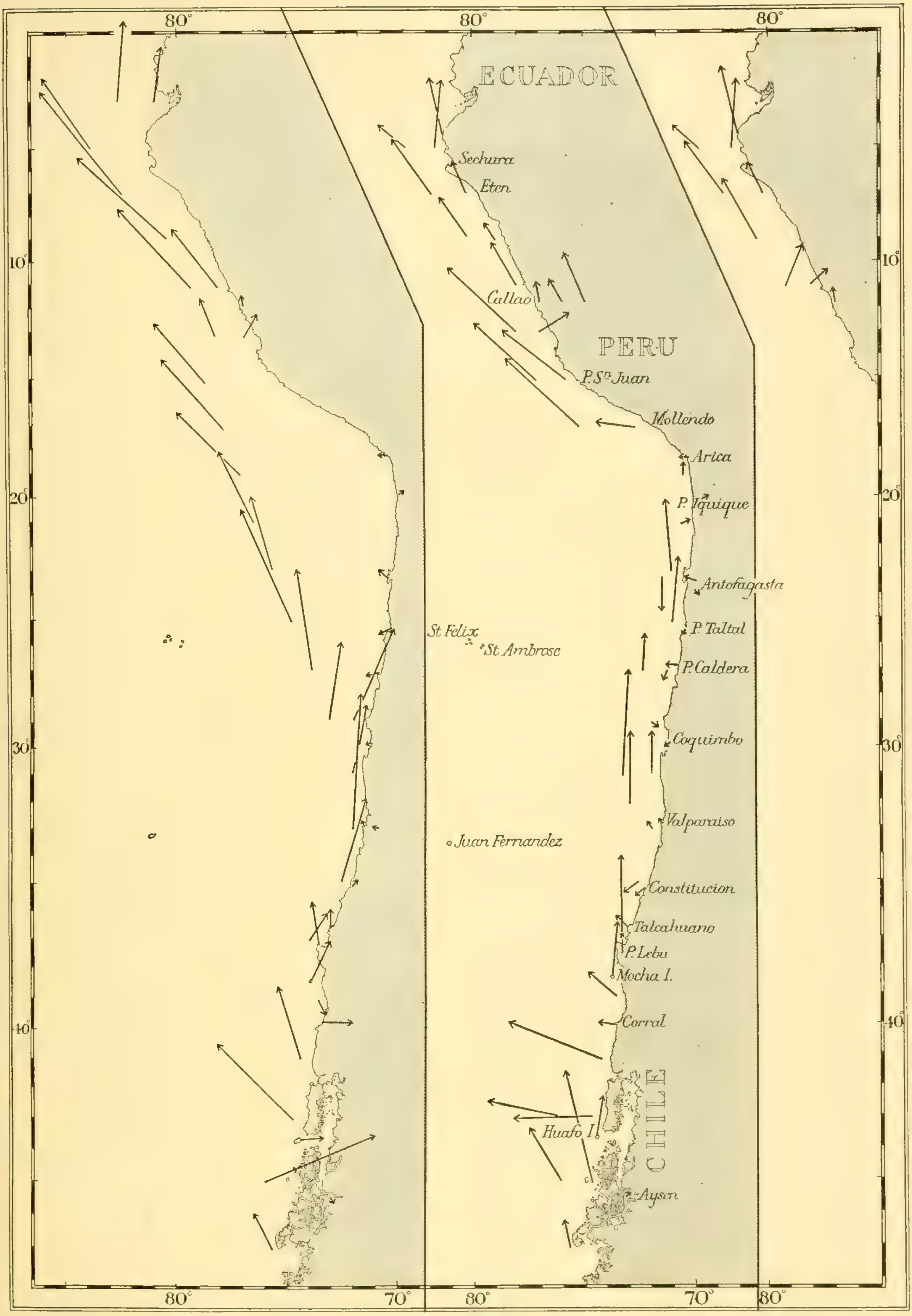

Fig. 4. Winds recorded during the period of survey. Left, August and September; centre, May, June and July (July 12–17 excepted); right, July 12–30. The arrows represent the residual wind (expressed as mean vectors); in the open sea and in the coastal zone, for observations in every two degrees of latitude; and at the Chilean meteorological stations for observations during a fortnight prior to the ship's arrival (see text and Appendices IV and V).

force, and this region has received the name of the "roaring forties". Here the depressions almost invariably pass to the southward and merely cause a variation of the wind from south-west to north-west. South of 50° S barometric depressions travel in an eternal procession from west to east, with their centres sometimes in about 50° S, sometimes near the Antarctic circle. On the northern sides of these depressions the winds are westerly, and on their southern sides easterly, hence along the trough of lowest pressure in 60° S, where the depressions are most frequent, the winds are very variable.

The departure of the coastal winds from directions more typically those of the trade winds is a constant feature of the coast and was noted by Dampier as early as 1684. It may be regarded as evidence of the fact that the surface air circulation of the Pacific, which reaches a total height of little more than 5000–6000 ft., is cut off from that of the Atlantic by the lofty barrier of the Andes. This has been suggested earlier by Mossman (1909):

> There can be little doubt that the influence of the mountain chain of the Andes in modifying the general circulation of the air is considerable, causing the coastal winds to conform to the shores of the littoral, and to blow parallel with the main axis of the Andean Cordilleras.

The suggestion made earlier, that the division between the areas of high and low pressure lay at the time of our survey in 38° S, is no more than approximation. Mossman has been able to give figures to show that in normal conditions the division is situated close to the 41° parallel.

Bowman (1916) draws attention to a wind of local importance in the sea-breeze which he describes as "without exception the most important meteorological feature of the Peruvian coast"; and the data he illustrates shows that this effect is conspicuous at least as far south as Iquique on the Chilean coast. Off Callao, diurnal periodicity was described at least as early as 1806 (Unanue). While the ship's movements prevented the collection of data in sufficient detail to illustrate the significance of this sea-breeze, our observations, and especially at Pisco (see Appendix IV, p. 259), are believed to lend some support to its existence. Bowman gives the following description of it:

> Several graphic representations are appended to show the dominance of the sea-breeze (see wind roses for Callao, Mollendo, Arica, and Iquique), but interest in the phenomenon is far from being confined to the theoretical. Everywhere along the coast the *virazon*, as the sea-breeze is called in contradistinction to the *terral* or land-breeze, enters deeply into the affairs of human life. According to its strength it aids or hinders shipping; sailing boats may enter port on it or it may be so violent, as, for example, it commonly is at Pisco, that cargo cannot be loaded or unloaded during the afternoon. On the nitrate pampa of northern Chile (20–25° S) it not infrequently breaks with a roar that heralds its coming an hour in advance. In the Majes Valley (12° S) it blows gustily for a half-hour and about noon (often by eleven o'clock) it settles down to an uncomfortable gale. For an hour or two before the sea-breeze begins the air is hot and stifling, and dust clouds hover about the traveller. The maximum temperature is attained at this time and not around 2.00 p.m. as is normally the case. Yet so boisterous is the noon wind that the labourers time their siesta by it, and not by the high temperatures of earlier hours. In the afternoon it settles down to a steady, comfortable, and dustless wind, and by nightfall the air is once more calm.

The possible influence of this factor in relation to the hydrology of the coastal waters is considered on pp. 210, 232 and 233.

CURRENT AND DRIFT OF THE SHIP

It was essential to the efficacy of our observations that the ship should cover long distances in the shortest possible time, and we were thus unable to include detailed current measurements in our programme; we were, however, able to record the combined effects of wind and current on the drift of the ship in a direction parallel with the coast which is here a component of major interest.

As explained on p. 120, the ship was steered regardless of lateral drift when steaming from one station to another in a direction normal to the coast. The track chart is therefore a graphic representation of the resultant effect upon the ship's course, of the components parallel to the coast, of wind, tide and current. The amount of this drift off different parts of the coast has been summarized in Table I. The drift is expressed in miles per day and is calculated from positions that had been fixed by Mr Davies, the ship's navigator, from observations of sun, stars or land bearings: dead reckoning positions have not been used in this calculation.

Northerly drift was experienced at irregular intervals over the whole surveyed region, but southerly drift only inshore and far out to sea off Peru; frequently no drift was noticeable. We may inquire whether it is possible to find out from any of these observations how much of the drift was referable to current and how much to wind.

On approaching Cape Carranza from the southward no wind was met, but a south-westerly set of 3 knots, possibly tidal, was recorded close inshore: the ship does not seem to have been under its influence when farther from shore between Sts. WS 593 and 596 (Fig. 7). The southerly drift experienced from 24 to 44 miles is almost certainly the result of northerly winds reaching force 4. Upon a change of wind to east-south-east at St. WS 599 the southerly drift changed to northerly. The conclusion is that there can have been no appreciable current off Cape Carranza.

On the second line, off Pichidanque Bay, no drift at all was recorded on the run westward, from which we can infer there was no current (Fig. 6). The northerly leeway experienced between Sts. WS 607 and 610 may be due to southerly wind, which during Sts. WS 608 and 609 reached a force of 5–6. These observations are of particular interest in showing that a mean drift of 20 miles a day can result from the direct action of winds in a region where before their advent no flow of surface water was apparent.

The track chart (Fig. 5) shows that the east and west courses off Caldera were subject to varying amounts of northerly and southerly drift, and this may be loosely related to changes of wind. This may be seen in Fig. 8, in which the amounts of northerly and southerly drift are plotted against wind records during the period from noon on June 4 to noon on June 6. The distance from shore at which the observations were made is also indicated. Northerly drift usually attended southerly wind and southerly drift usually attended northerly wind, but a strong southerly drift against the wind within 2 miles of the coast is evidence of a counter-current inshore. At 11–27 miles from shore northerly drift was recorded during calm weather following a period of northerly winds: while this

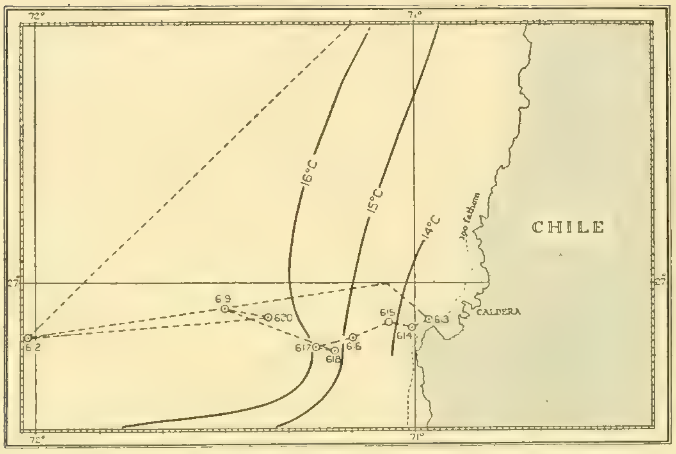

Fig. 5. Caldera. Track of R.R.S. 'William Scoresby', June 4–6. Courses set east and west, except on the limb immediately before St. WS 613. St. WS 612 was revisited after completion of St. WS 620. In this and the following charts, the track of the ship is shown as a thin broken line, and the surface isotherms as heavier continuous lines.

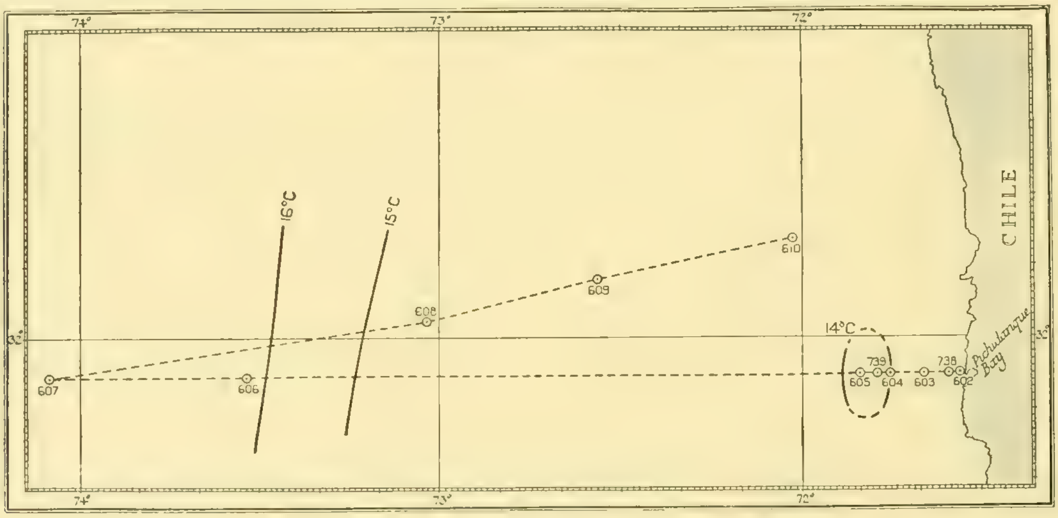

Fig. 6. Pichidanque Bay. Track of the ship, May 28–30. After St. WS 602 course set 270°; after St. WS 607 course set 090°.

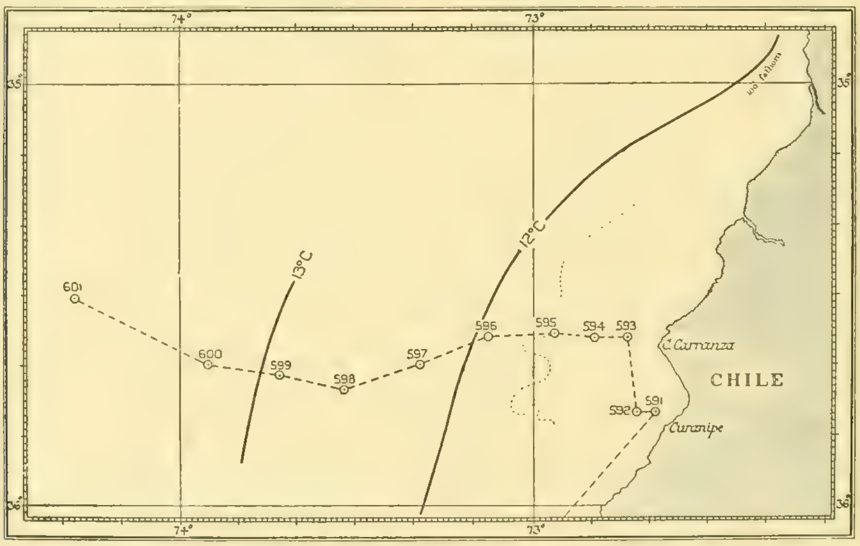

Fig. 7. Cape Carranza. Track of the ship, May 18–20. After St. WS 593 course set 270°; after St. WS 601 course set 280°.

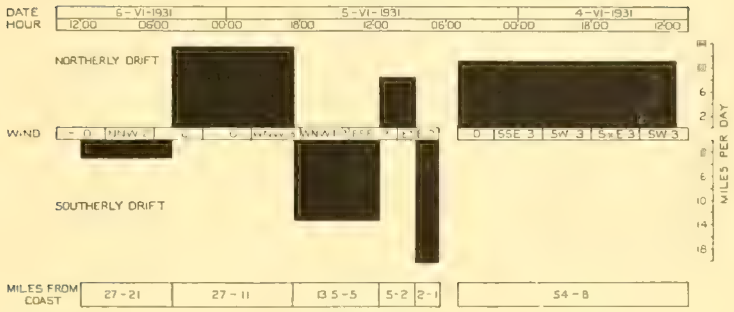

Fig. 8. Drift of the ship in a north and south direction, from noon on June 4 to noon on June 6, illustrated diagrammatically from right to left. The data are given in Tables I and Appendix IV. The northerly drift from noon on June 4 to 0507 on June 5 includes the time spent on St. WS 612, and the passage to within 8 miles of land (see Fig. 5); the subsequent drift, alternately south and north, took place while Sts. WS 613–620 were being worked. Four-hourly records of wind are given in the centre of the diagram, while below is appended the distance from land at which each of the observations was made.

might be regarded as evidence of northerly current we believe the data too few for definite information.

On the journey out from Antofagasta the wind blew at first east, and then unremittingly from the south with force 4, which increased to 5 from south-south-west in the open sea; during some 36 hours from Sts. WS 622–630, the ship drifted 11 miles to the northward, i.e. a mean drift of 8 miles a day. According to the track chart, however, the greater part of the drift occurred within the coastal 15 miles, and as in addition the drift had an appreciable westerly component, the mean rate exceeded 12 miles a day. Since the greater drift accompanied the lesser wind, some may be ascribed to currents.

The return journey commenced with moderation from force 5 to 2 in the southerly wind which later changed direction to the north; in spite of this the ship was carried in a north-easterly direction as may be inferred from the positions at the beginning and end of St. WS 630, during which the ship was drifting for 12 hours (Fig. 9 and see p. 145). A heavy counter-current was met inshore off Bahia Herradura.

On a later page, the surface drift off Antofagasta will be related to changes of surface temperature: it is therefore of particular interest that the positions of stations in this locality (Fig. 9) have been fixed with exceptional accuracy: those of the first seven (Sts. WS 622–628) and the last six (Sts. WS 630–635) by cross-bearings on land and that of St. WS 629 by observations on a sunny day; the ship's track is in consequence a faithful record of her drift, but of the relative velocity of this drift on different points of this line, it is misleading because there is no indication of the time spent on any one part of the line.

Winds inshore off Arica amounted to light airs, yet a north-westerly drift of 48 miles a day was noted, which must be due to inshore current (Fig. 11).

The amount of drift and set experienced at various points along the San Juan line of stations is of interest (Fig. 11). A strong wind from the south-east blew for almost the whole period. Close to the shore its force attained 6–7 and drifted the ship to

Table I. *Showing drift recorded by R.R.S. 'William Scoresby'*

Position	Date	Distance from shore	Drift observed	
			Direction	Miles per day
Santa Elena	31. vii–1. viii. 31	0–50	—	0
Gulf of Guayaquil:				
lat. 2–3° S	1. viii. 31	80	ENE	24
		50	NW	34
lat. 3–4° S	2. viii. 31	90	NW	31
Capo Blanco	25. vii. 31	0–2·5	S	58
		2·5–21	N	18–24
Punta Aguja	21–23. vii. 31	1–33	N	36
		33–100	N	6
		100–171	SW	14
		171–204	—	0
Lobos Islands	17–18. vii. 31	6–33	NW × N	36
		33–54	NE × N	24
		86	SW	36
		128	W	30
Guañape Islands	10. vii. 31	8–27	NW	12
Callao	20–21. viii. 31	6–19	—	0
		19–155	N	3
	1–2. vii. 31	6–24	—	0
		24–103	N	17
San Juan	23–24. vi. 31	64–84	NW	2
		84–152	SE	6
	22–23. vi. 31	2–13·5	NW	24
		13·5–99	NW	10
		99–152	NW	19
Arica*	19. vi. 31	4–11	NW	48
Antofagasta	9–10. vi. 31	0–1·5	S	38
		1·5–6·5	—	0
		6·5–17	N†	24
		17–46	N†	8
	8–9. vi. 31	0–14·5	N‡	11
		14·5–46	N	6
Caldera	5–6. vi. 31	1–2	S	21
		2–5	N	8
		5–13·5	S	14
		11–27	N	14
		21–27	S	3
	4–5. vi. 31	8–54	N	11
Pichidanque Bay	29–30. v. 31	25–129	N	20
	28–29. v. 31	0–129	—	0
Cape Carranza	18–19. v. 31	4·5–24	—	0
		24–44	S	14
		44–64	N	10

* Dead reckoning indicates negligible drift at > 16 miles.
† Plus considerable easterly component.
‡ Plus westerly component.

leeward of her outward course which was maintained at 224°. During her run from 25 to 100 miles from the coast the force of the wind and drift eased but thereafter increased again, rising to force 5 and increasing also the amount of her drift on the end of the line. On her return run on a course of 44° from Sts. WS 653 to 657, the force of the wind lessened gradually from 5 to 4·5, and with it the drift from 12 miles a day to zero. When the wind decreased further to force 4, the ship drifted against it. It appears therefore that during the 58 hours from Sts. WS 647 to 657, while the ship's course was maintained at 224° on the outward and 44° on the inward run, the total drift including leeway amounts to no more than 8 miles a day. In similar wind conditions off Pichidanque Bay where there was no observable current, the recorded amount of drift was more than twice as great. It seems necessary therefore off San Juan to postulate an offshore current flowing south-east against the wind.

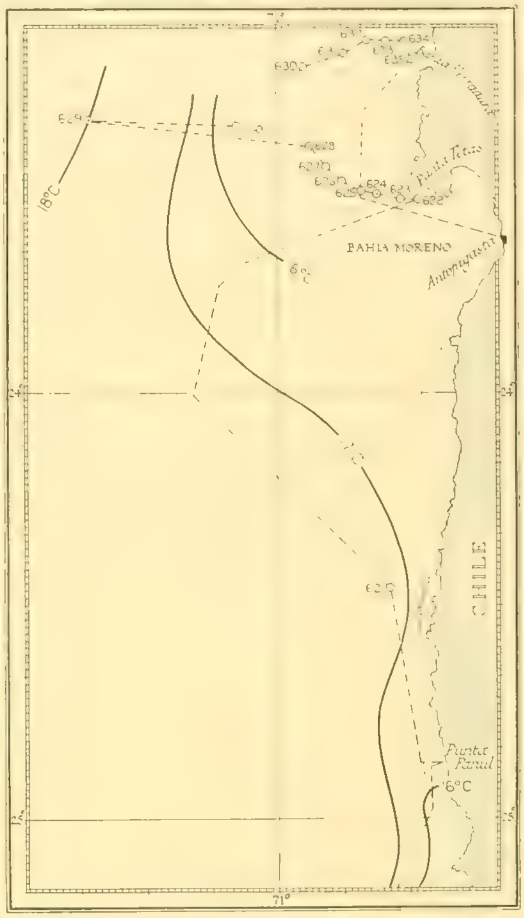

Fig. 9. Antofagasta. Track of R.R.S. 'William Scoresby', June 7–10. St. WS 630 was worked between the two positions shown. Course set 270° from St. WS 622 and 090° from St. WS 629.

Current was shown to be absent within 24 miles of the Callao coast by observations of discoloured water at the Palominos Island control stations and by the well-fixed positions of Sts. WS 663–666 (Fig. 10). At farther distances from the shore a leeward drift of 20 miles in the space of 28 hours (the period between Sts. WS 666 and 671) accords with the drift experienced on other occasions. Observations of discoloured water off Palominos Island were first made on June 26, when a patch cinnamon rufous in colour lay south of San Lorenzo Island, its northern margin coming to an abrupt end opposite Palominos Island (Plate XVI, figs. 7 and 8). The boundary line between the cinnamon rufous and the clear water of porcelain blue northwards formed so striking a line of demarcation that it was kept under observation for several days. It was revisited on July 1 and 15, and in that time, although it had grown less distinct, it had not drifted farther northwards than the northern end of San Lorenzo, a distance of some 4 miles. When observations were repeated in August, current was again insignificant.

Off the Guañape Islands northerly drift amounted to 12 miles a day, rather more than would be accounted for by the southerly wind of force 1–2 which prevailed at the time, and some of this must therefore be attributed to current (Fig. 13).

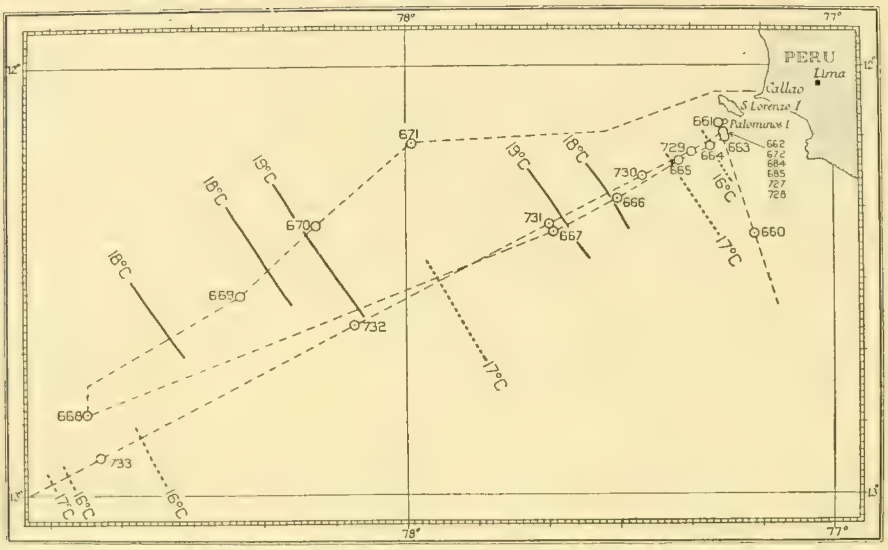

Fig. 10. Track of R.R.S. 'William Scoresby' off Callao. Sts. WS 663–671 were carried out on July 1–3, Sts. WS 728–734 on August 20–21. Isotherms in July are shown as continuous, in August as broken lines. After Sts. WS 663 and 728 course set 242°, after St. WS 668 course set 062°. Stations listed on the site of WS 662 are control Stations.

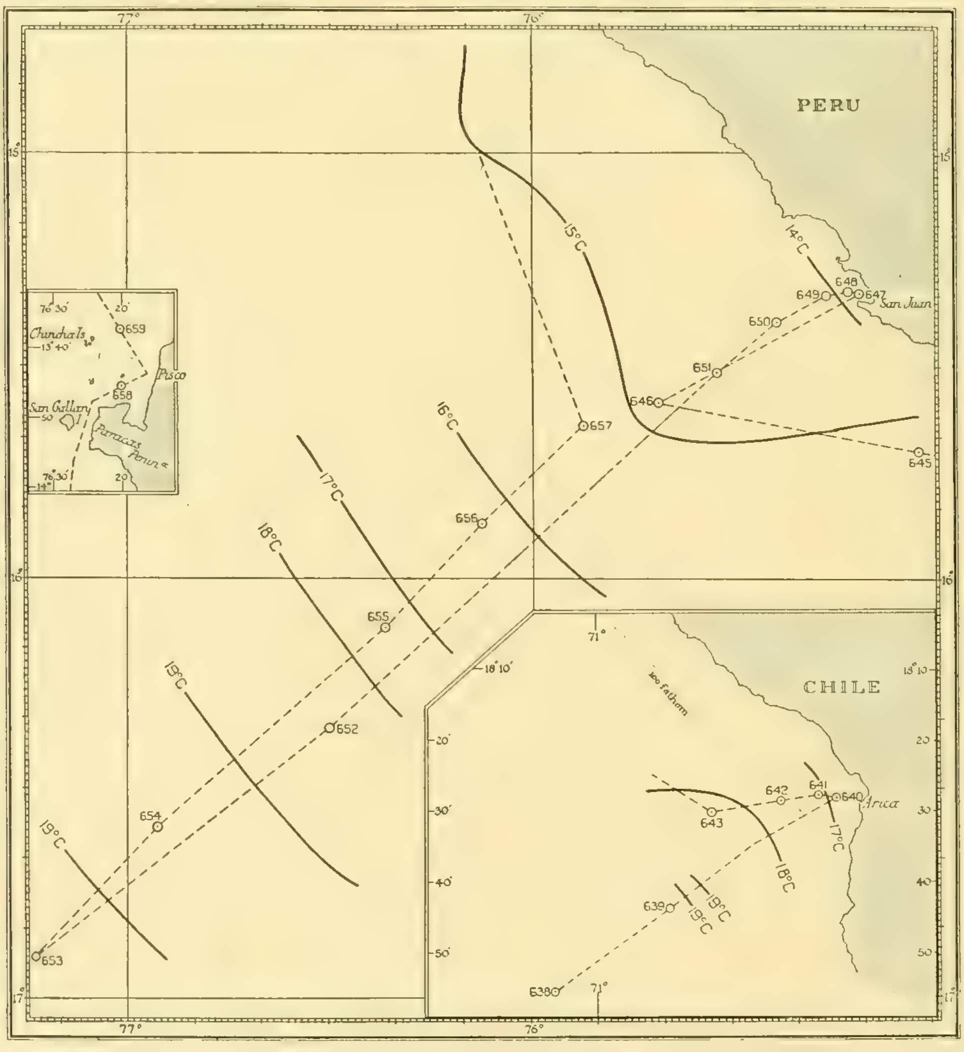

Fig. 11. San Juan. Track of the ship, June 22–24. Inset left: stations in Pisco Harbour (June 25). After St. WS 647 course set 224°, after St. WS 653 course set 044°. Inset right: track of the ship off Arica, June 19–20. After St. WS 640 course set 238°.

When shaping courses to take observations midway between the Lobos de Afuera and the Lobos de Tierra, allowance was made as far as possible for the effects of drift and set which were pronounced on all parts of the line (Fig. 12). At 116 miles offshore the drift of 30 miles a day was almost due westerly (264°): at 78 miles offshore 36 miles a day south-westerly (213°): to the westwards of the Lobos de Afuera (45 miles from the mainland) the drift was north-easterly (032°) with a velocity of 24 miles a day, and between the two archipelagoes and at distances of less than 20 miles from the mainland the drift was north-westerly with a velocity of 36 miles a day. The winds during this time were on the whole light, and drift, at any rate inshore, must be ascribed very largely to surface currents. This accords with the traditional records of current off this stretch of the coast (p. 190).

A considerable current affected the ship within 33 miles of Punta Aguja. The total drift northwards was 18 miles in 12 hours. In a slightly stronger wind off Pichidanque Bay where there was no current the ship had drifted at 20 miles a day. Allowance for wind off Punta Aguja would thus leave a clear balance of 16 miles a day which can be attributed to the northerly current. Between 100 and 171 miles offshore a south-westerly current appears to have drifted the ship at 14 miles a day against a wind force 1–2 from south-east and south-south-west.

The currents off Capo Blanco were complicated by the intrusion along the coast of hot water of low salinity southwards from the Gulf of Guayaquil and the coast of Ecuador. Local currents were very strong: while the ship was working a station in the hot water inshore a south wind blew with a force of 5–6 strong enough to give her a northward leeway drift of some 18 miles a day. But against the wind a surface current raced southwards at an estimated 48–96 miles a day, and overcoming the effect of the strong wind, carried the ship southwards at 41 miles a day. Farther from the shore the current weakened (Fig. 70).

Off the Gulf of Guayaquil itself three records indicate that surface movement is considerable (see Table I): but within 50 miles of Santa Elena none was recorded.

These data suggest that the ship's drift has been caused to a great extent by wind. Estimations of northerly drift resulting from the action of current alone indicate that it had a velocity of 16 miles a day off Punta Aguja and of 48 miles a day off Arica; considerable current was noted off the Lobos Islands but less off the Guañape Islands, Antofagasta and Caldera. Off Cape Carranza, Pichidanque Bay, Callao and Santa Elena the ship's drift seemed to be entirely due to windage. Off Capo Blanco, San Juan, northwards of Antofagasta and Caldera, southerly currents were also recorded.

Inferences of a general character may be made by averaging the drift at different distances from the shore. The mean drift off Chile and Peru separately and off the west coast as a whole is illustrated in Figs. 14 and 15; the first gives the mean gross drift in both northerly and southerly directions; the second gives the mean residual drift either north or south after subtracting the lesser from the greater. A key showing the number of observations averaged at different distances from the shore is given beside each graph.

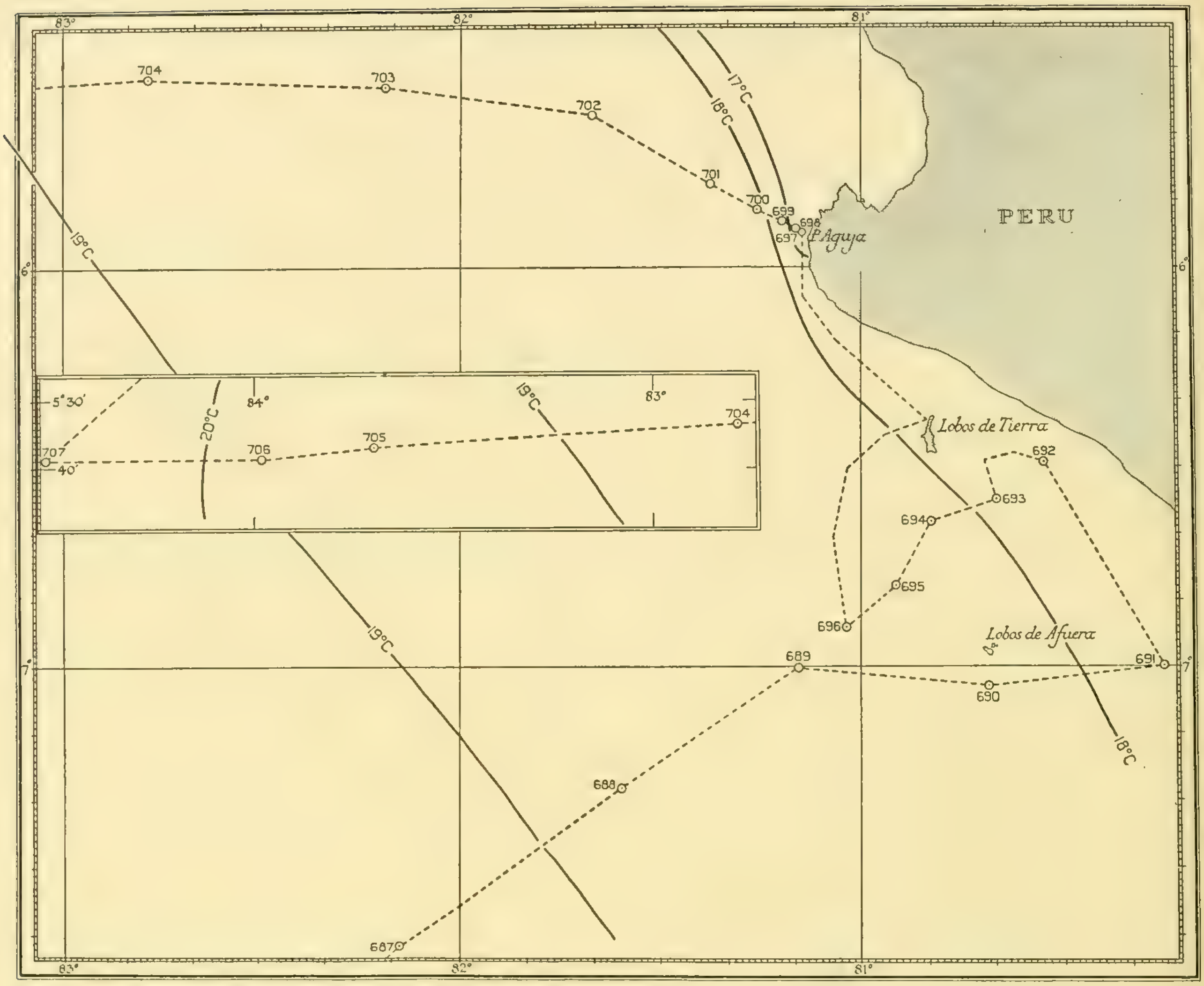

Fig. 12. Track of R.R.S. 'William Scoresby' off the Lobos Islands, July 17–20; and off Punta Aguja, July 21–23. Inset: Sts. WS 704–707 off Punta Aguja. After St. WS 696 course set 270°.

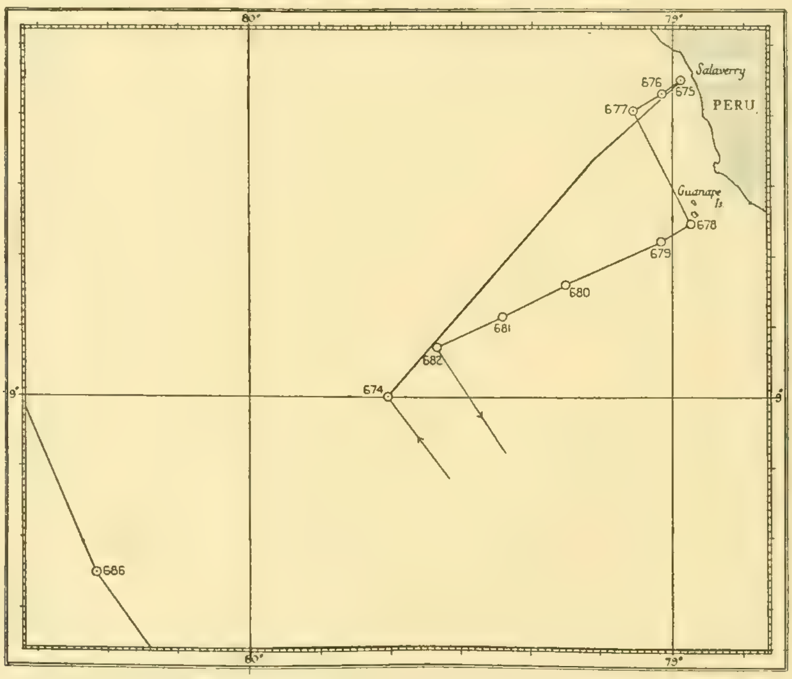

Fig. 13. Guañape Islands. Track of the ship, July 9–11; St. WS 686 was carried out on July 17. The distribution of surface isotherms is shown in Fig. 34. After St. WS 678, course set $238\frac{1}{2}°$.

The drift in a direction parallel to the coast was found on the whole to be weak. It was greater inshore where it had a mean velocity of 10–12 miles a day, than at a distance of 100–130 miles where the mean velocity in a direction parallel to the coast was

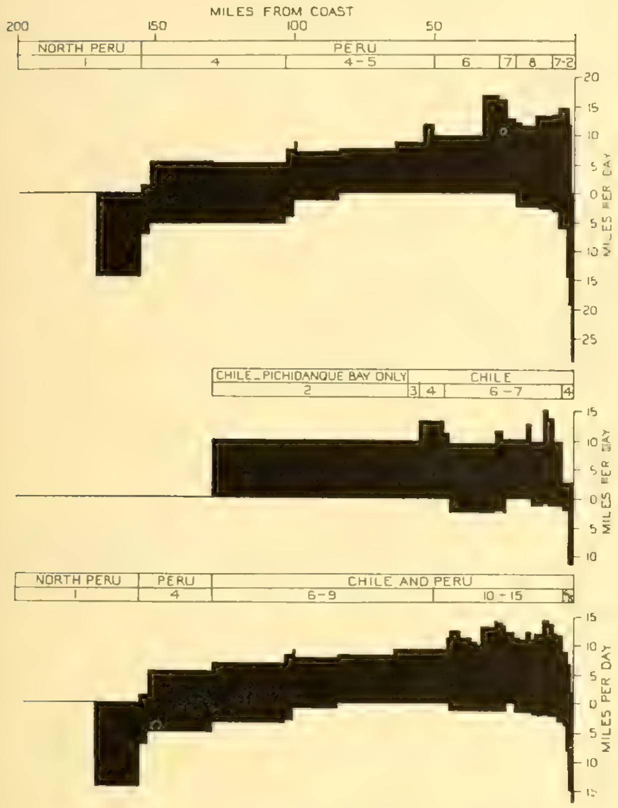

Fig. 14. Diagram illustrating the ratio of northerly to southerly drift (respectively above and below base-line) at different distances from the coast. The data are plotted separately for Peru (uppermost) and for Chile (centre); and in combination for the west coast as a whole (lowermost). The drift, expressed as miles per day, represents the mean drift of the ship in a direction parallel to the coast; and is computed by dividing separately the total amounts of the drift in each direction by the total number of observations in both directions.

Fig. 15. Diagram illustrating the mean residual drift at different distances from the coast. The drift of the ship in a direction parallel to the coast is expressed as miles per day and is computed by dividing the difference between total drift towards the north and towards the south, by the total number of observations. The data are plotted separately for Peru (uppermost) and for Chile (centre); and in combination for the west coast as a whole (lowermost).

only $3\frac{1}{2}$ miles a day. There was no sudden change from the zone of heavier drift to that of lesser drift, but the mean values over the whole coast showed a slow reduction with increasing distance from shore. Observations on drift at distances beyond 130 miles were made on only four lines, and these being off Peru are insufficient to allow of generalizations.

TEMPERATURE

Figs. 16 and 17 show that surface isotherms are generally parallel to the coast, thereby emphasizing the contrast between inshore and offshore temperatures: the temperature off southern Chile is less than off northern Peru, and isotherms consequently slant gradually towards the coast. If we sail out to sea across the current we find that the temperature of the water rises as the distance from land increases, and at 50–100 miles or more it is higher by 1–5°. During the present survey this rise varied at every point along the coast as shown by the irregularity of the curves in Figs. 29 and 30, and the positions of isotherms vary greatly at different times and in different localities.

Off the Peruvian coast lay a wedge of warmer water, whose temperature was higher than that of adjoining waters east and west. It shows as a dome-shaped hump in the graphs of surface temperature (Fig. 30) for the Lobos Islands, the Guañape Islands, Callao, San Juan, and possibly also for Arica (Fig. 29); off San Juan, off Callao in July, and off Callao in August, this warmer water had a breadth of about 50 miles at distances offshore of respectively 100–150, 25–75, and 10–60 miles (p. 148 *et sqq.*). On these lines the observations extend beyond the warm water to cool temperatures, but the Guañape Islands line terminated before the warm water was crossed. The warm-water wedge lies therefore on the edge of the area examined, and the observations may be too few fully to determine its character. In Fig. 16 the available data are contoured as straightforwardly as possible. An alternative if not more attractive theory is discussed on p. 192.

The difference between the temperature of the warm-water wedge and that of adjoining oceanic water to the west was small but never indistinguishable between the parallels of 17 and 6° S, from June 22 to August 20. Off San Juan this warmer water seemed different from the cooler surrounding water, and its fauna contained species such as flying fish which were never found in the cooler waters. Here also the wedge appeared to differ in its movement (see p. 129). In the northern part of the region the wedge was relatively less warm than surrounding water but could still be recognized. Its distance from the shore may be placed at 50 miles off the Guañape Islands, 140 miles from the Lobos Islands, and 180 miles off Punta Aguja. Its western margin in these latitudes was ragged, irregular and ill-defined, and its nature as a distinct body of water less well established. Off Punta Aguja its western margin (the isotherm of 20° C.) left the area of our investigations.

The northern boundary of the Peru Current off Capo Blanco is clearly discernible, the surface temperature showing a reversal of the conditions found farther south. Off Capo Blanco the hottest water lay near the coast, but in the space of 22 miles the surface temperature dropped to the level formerly found inshore off Punta Aguja. The Peru Current, hitherto coastal, seems to have swung out to sea, and cutting across the line of stations off Capo Blanco seems to have been pursuing a west-north-westerly course towards the Galapagos Islands; inshore a tongue of hot water projected southwards from the Gulf of Guayaquil.

In the following pages the isotherms in vertical section and in surface plan will be examined with a view to tracing correlations between them and such factors as wind, surface drift, salinity, phosphate and plankton distribution, and the colour of the water.

45–35° S: CAPE CARRANZA

The climate is temperate and the southerly regions are drenched in heavy rainfall, the surface salinity being thereby reduced (see Fig. 18 and p. 159). At the surface the isotherm of 12° C. followed the ship's track from south to north for as much as 600 miles; and beneath the surface, similar thermal uniformity is shown, isotherms being spaced widely apart and the temperature sinking but 5° through the depth of 400 m.: salinity shows, however, that the water is distinctly layered (pp. 159–163).

Off Cape Carranza the water was, in appearance, actively welling up, but in view of the fact that no drift was noticed at the surface, and of the fact that the ship enjoyed calm weather, the wind being in the north, this appearance of upwelling may be a relic of earlier activity. Comparable conditions in other localities will later be seen to suggest a reversal of upwelling, and the possibility should be borne in mind that subsidence of the cool surface water may have been in progress off Cape Carranza at the time of our visit. Upwelling is shown to have been extensive for some considerable time in the past by the high content of phosphate and of plankton of the upper layers (pp. 182 and 184).

The surface temperature rose steadily from 11·45° C. inshore to 13·57° C. at 58 miles offshore, after which the rise was less, reaching 13·65° C. at 83 miles offshore (Fig. 29). If the inshore water at this time were really subsiding as suggested, the lowermost of the isotherms and isohalines formerly showing upward movement might at the time of our visit have regained horizontal stratification. If this were so, the sections illustrated in Figs. 18 and 19 would no longer indicate the depth previously involved in upwelling.

After the light airs that had prevailed up to St. WS 596, a north-north-east wind arose reaching force 4, and this coincided with warm water at the surface at St. WS 597. This suggests at first that wind from the north had driven warmer water southwards, but the same wind persisted at St. WS 598 where cooler water was again met with.

35–30° S: PICHIDANQUE BAY

Over this 300-mile stretch of coast the water becomes rapidly warmer and the weather as recorded at Valparaiso was calm; surface isotherms instead of running parallel to the coast slant steeply towards it.

At the end of May, Pichidanque Bay was still enjoying a period of calm that had been in existence for some considerable time. Warming up of the surface layers had led to a mean inshore temperature of about 14° C., while a temperature of 11·45° C., found at the surface at Cape Carranza, was here at 40–70 m. depth. A poverty of phytoplankton and zooplankton such as was not found at any other locality examined and extreme depletion of phosphate are signs that for many weeks past the upper layers cannot have been replenished with nutrient salts, or at any rate only on a very modest scale.

Sections (Figs. 20 and 21) indicate that mild upwelling had been taking place, for the isotherms and isohalines curve slightly upwards near the coast, yet on our arrival on

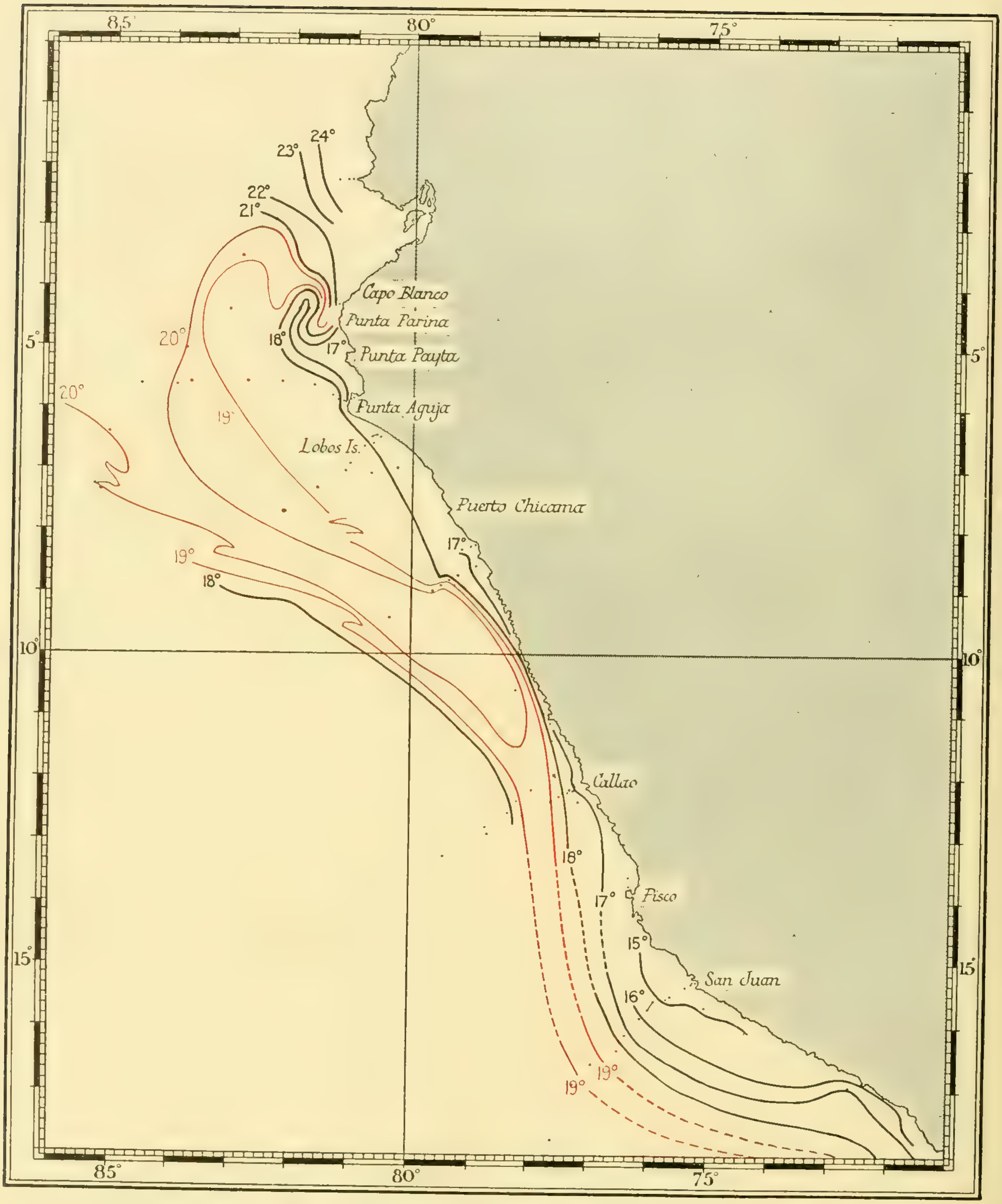

Fig. 16. Distribution of surface isotherms off Peru, June to August, 1931. An alternative construction is placed on the same data in Fig. 63.

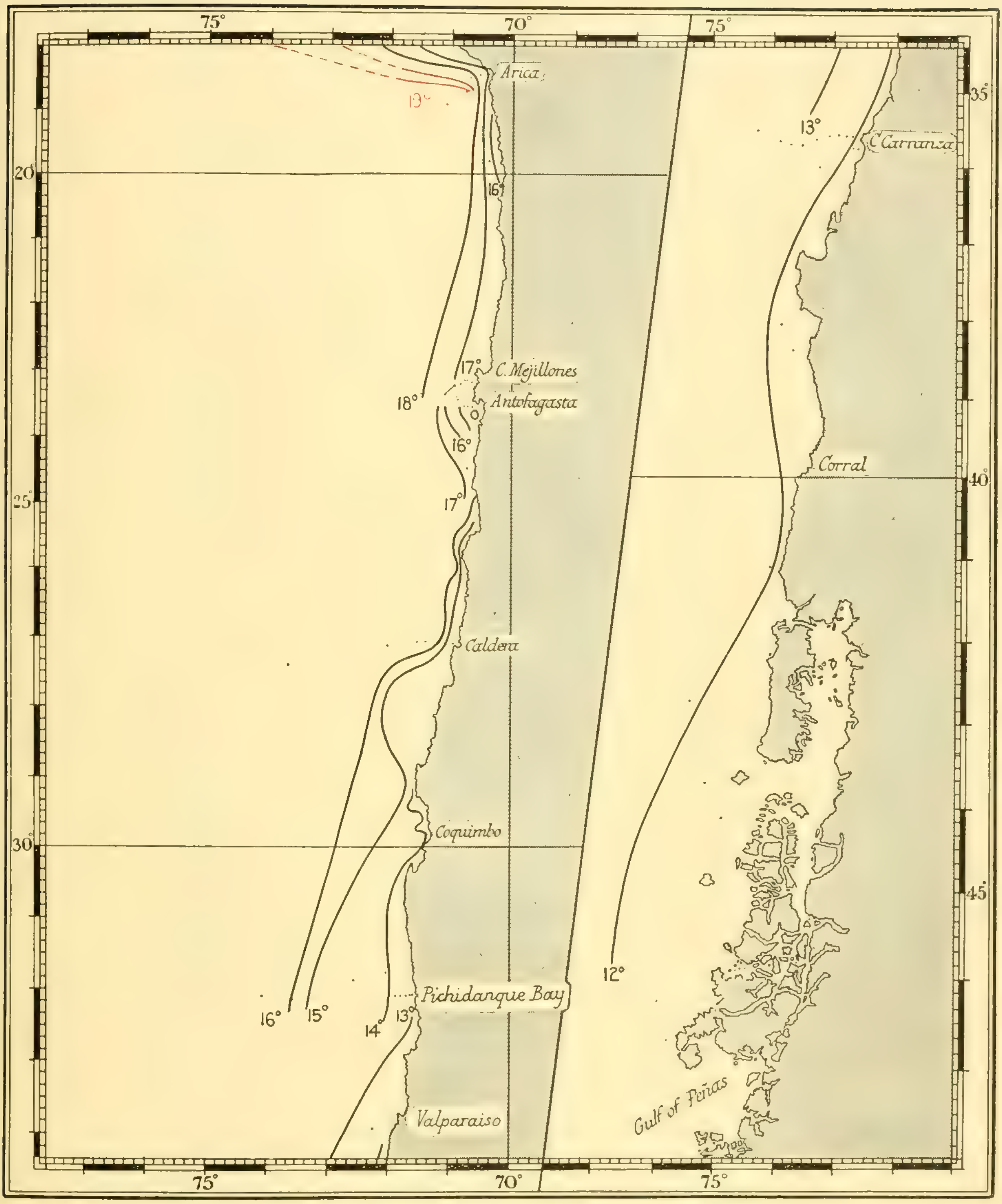

Fig. 17. Distribution of surface isotherms off Chile, May to June, 1931.

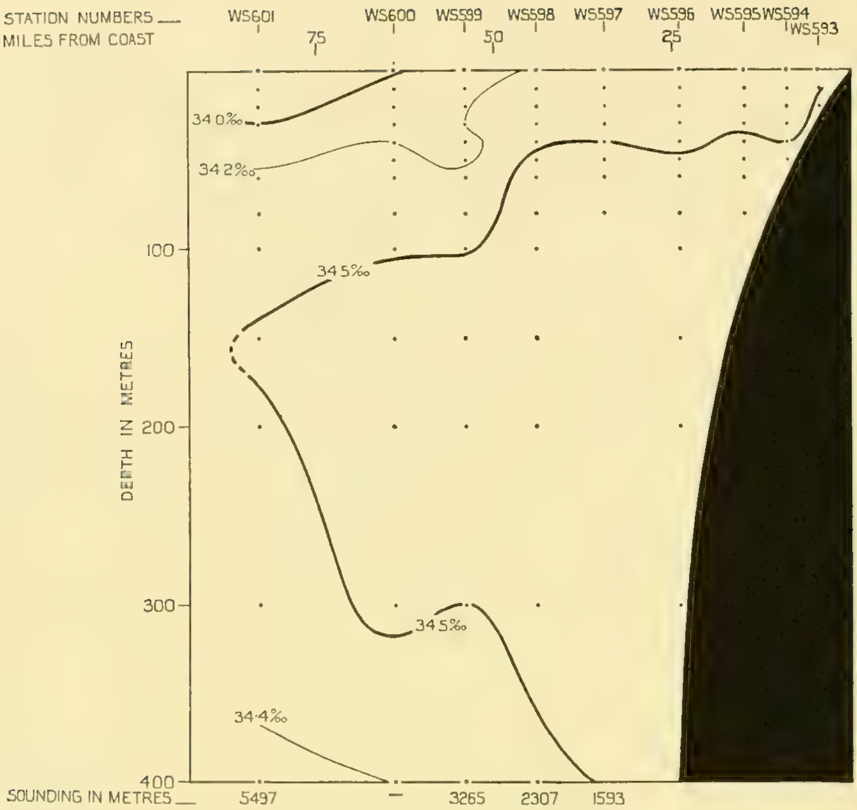

Fig. 18. Distribution of salinity. Section off Cape Carranza, May 18–20.

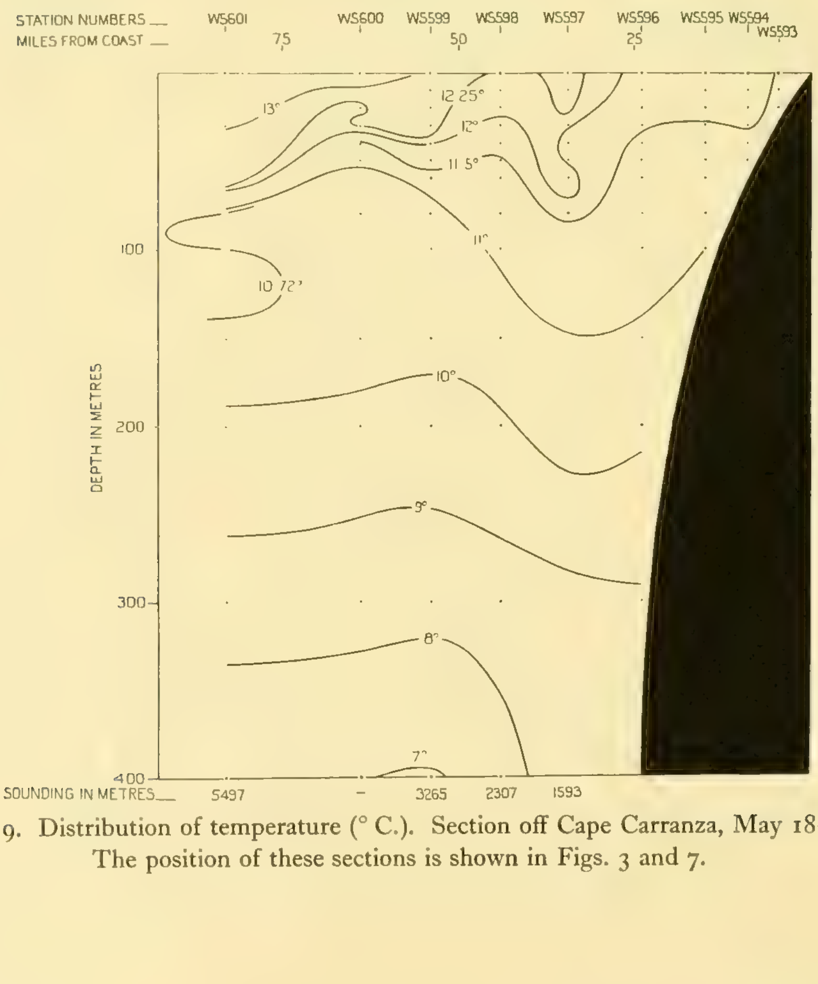

Fig. 19. Distribution of temperature (° C.). Section off Cape Carranza, May 18–20. The position of these sections is shown in Figs. 3 and 7.

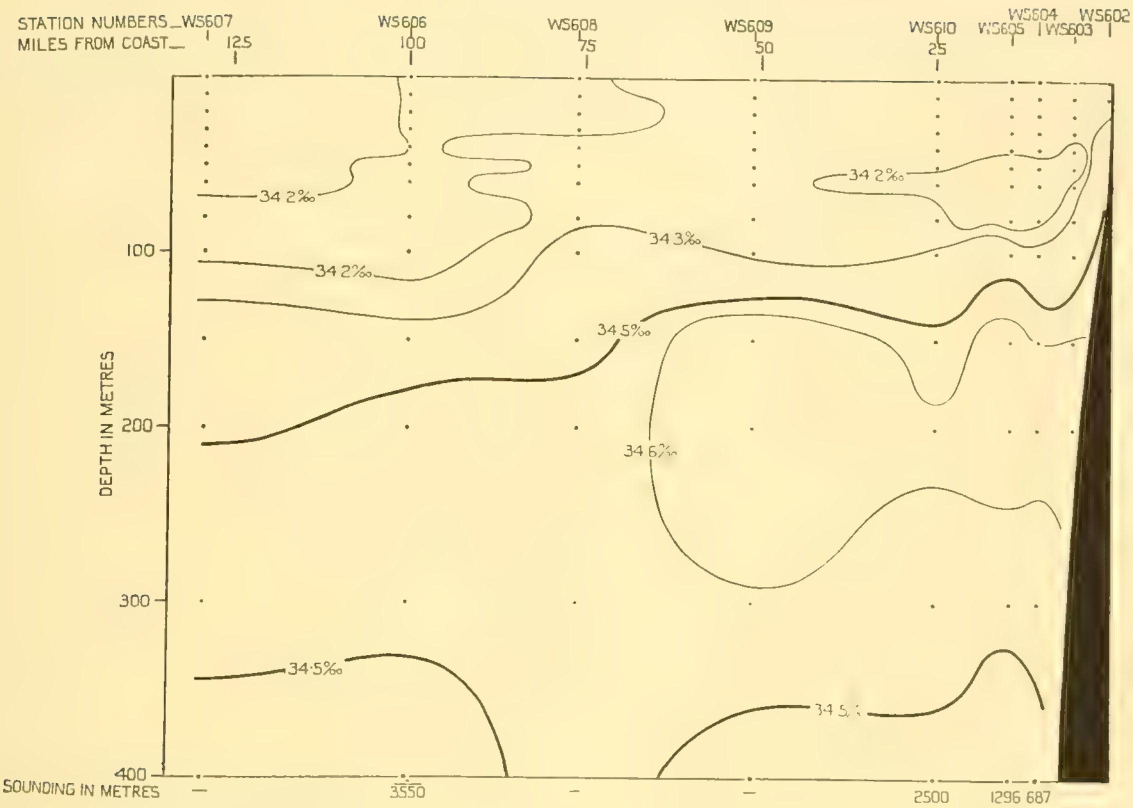

Fig. 20. Distribution of salinity. Section off Pichidanque Bay, May 28–30.

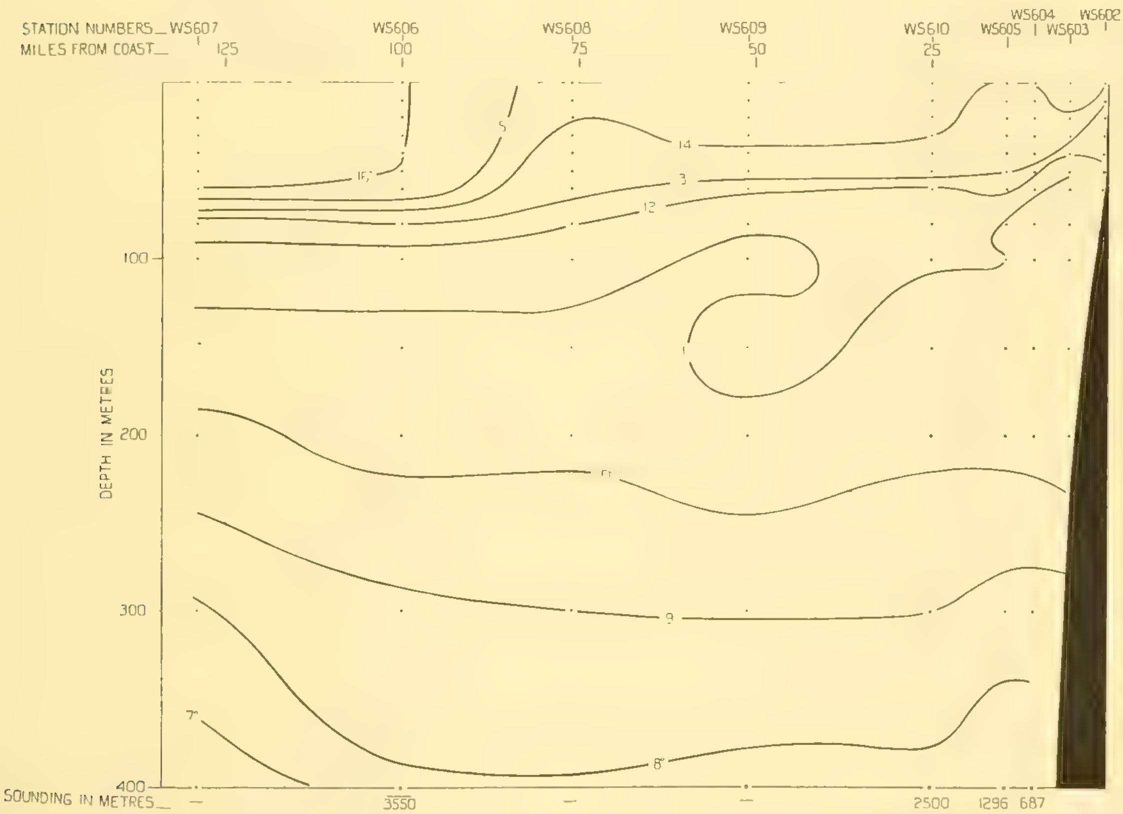

Fig. 21. Distribution of temperature (° C). Section off Pichidanque Bay, May 28–30. The position of these sections is shown in Figs. 3 and 6.

May 28, wind was either absent or blew gently from the south-west, and no immediate connection is to be supposed between this wind and water at this depth. On the other hand, the association between cool water at the surface and the easterly wind at Sts. WS 604 and 605 is suggestive of a direct relation.

After completion of Sts. WS 606 and 607 in the open ocean, a strong southerly wind arose which drifted the ship northwards as shown in Fig. 6. The possibility that the upwelling noted in Fig. 21 may be an indirect effect of this wind is discussed on p. 210.

30–25° S: CALDERA

The inshore water at Caldera showed signs of active upwelling, and immediately to the southward cold water was met at the surface as far out as 33 miles. Elsewhere, however, warm water was close to the coast and inshore winds were northerly. Irregularities of surface temperature as found in this region (Fig. 17, Tables XX and Appendix IV) are frequently met with where warm and cool water meet; but while convergence of the warm water with the cool inshore, and a ragged boundary between the two, may be consistent with a recent change of inshore wind to the north, the question whether the cool water was upwelling at the same time has not been decided.

The changeable condition met with on the surface, also noted in reference to wind and drift in Fig. 8, extends to the subsurface layers and is illustrated in the temperature section off Caldera in which almost phenomenal irregularity is shown (Fig. 23). An eddy-like movement beneath the surface at 10–15 miles offshore, Sts. WS 616 and 618 may indicate a sinking of newly mixed water. Witte's (1910) account of the theory underlying this phenomenon may be quoted:[1]

> When on the boundary of an ocean current, warm water of high salinity is brought into contact with colder water of less saline character, but having approximately the same specific gravity, then the resulting mixture will, as may easily be proved by the Knudsen tables, be of greater density than either of its component parts. It will consequently sink down, giving rise to the peculiar phenomenon known as "cabbeling".

Comparison of the temperature, salinity and density of the upper 20 m. at Sts. WS 614–620 shows that these conditions come near to fulfilment (Table II). Thus if surface water from Sts. WS 617 and WS 615 were mixed in the ratio of 5 : 8, the mixture would have a salinity similar to water at St. WS 618 (34·36 °/₀₀) but with a density of 25·94. This value would not be in equilibrium with surrounding water until it had sunk to a depth of about 40 m.

Inshore upwelling at Caldera (Fig. 22) cannot be traced to greater depths than 100 m., but offshore, upwelling may be traced to a depth of 250–300 m. The inshore water at these depths is seen to have a higher temperature than water in the open ocean; later it will be shown to be a highly saline return current having a southerly flow—it is a coastal current: the offshore water is lighter, is sub-Antarctic in character, and probably has northerly flow (Fig. 22).

No adequate idea of water movement can probably be obtained from a single line of

[1] Translation from Sandström (1919).

stations in such a turbulent neighbourhood. Streams of water may have been rising or falling across the plane of the section and may have been the cause of repeated fouling of the wires used with hydrological instruments. Two of these wires are used simultaneously on one side of the ship, one forward and the other aft, for working the deep- and shallow-water bottles, and they are well weighted with sinkers: the wires rarely fouled one another, but on this line at St. WS 616, they were continually becoming twisted round one another until eventually it was found impossible to have them both working at the same time.

Table II. *Comparison of temperature, salinity and density off Caldera, June 5–6*

	Depth m.	Station					
		WS 620	WS 617	WS 618	WS 616	WS 615	WS 614
Temp. ° C.	0	16·50	15·90	15·10	14·88	14·20	13·45
	10	16·21	15·90	14·22	13·90	14·21	13·45
	20	16·18	15·65	13·80	13·35	13·50	13·40
Salinity ‰	0	34·45	34·44	34·36	34·34	34·31	34·31
	10	34·44	34·44	34·28	34·32	34·34	34·36
	20	34·44	34·44	34·35	34·36	34·37	34·35
σt	0	25·21	25·35	25·46	25·49	25·62	25·77
	10	25·27	25·35	25·59	25·69	25·64	25·81
	20	25·28	25·40	25·73	25·83	25·81	25·81

25–18° S: ANTOFAGASTA AND ARICA

The hydrology of this stretch of the coast bears a resemblance to the preceding, in that surface temperature was uniformly high except at Antofagasta where low temperatures were conspicuous. The general uniformity of surface temperature may be traced to warmth in the southern part of the region resulting from the northerly winds already noted between the parallels of 26–30° S, and in the north to marked upwelling resulting from strong inshore current. Upwelling at Antofagasta seemed in a more active phase than at Caldera, since the upper layers of the highly saline return current were found at the surface. In other respects temperature sections from both localities agree in showing that the upwelling water was drawn mainly from the less saline sub-Antarctic water; compare Figs. 22 and 23 with 24–27.

Conditions at Antofagasta were also very changeable. After the ship had worked her outward line of eight stations (Sts. WS 622–629, Figs. 24 and 26), it was necessary to repeat a second line of observations (Sts. WS 630–635) on the return shorewards, this time a little farther to the north owing to the drift of the ship; for within the short interval of 30 hours, the temperature, salinity and phosphate distribution had changed considerably.

On the outward journey the surface temperature inshore was about 14° C. and did not show the usual rise for some 10 miles when it suddenly jumped up $3\frac{1}{2}$° in 21 miles

and reached 17·59° C., a gradient comparable to the rise off Caldera (Fig. 29). There was little further rise, the temperature touching 18·04° C. in the course of work on St. WS 629 at 46 miles offshore. Wind blew from the east and south with force 4 which increased to 5 from south-south-west in the open sea. During this time the ship's track from Sts. WS 622 to 630 deviated 11 miles to the northward, and in addition the drift had an appreciable westerly component (Fig. 28).

The return journey commenced with a moderation from force 5 to 2 in the southerly wind which later changed direction to the north; but before any change in the direction of the wind was noticeable, the water temperature at this distance from shore had altered and the surface isotherms had closed with the coast. Whereas on the outward run the temperature rose sharply between 10 and 21 miles offshore and from 31 to 46 miles had undergone no change, on the return journey the temperature fell from 17·9° C. and followed an even curve, dropping at first slowly and then rapidly until it reached 14·9° C. at 2 miles from shore (Fig. 29). Thus the temperature was generally warmer; the isotherms of 17, 16 and 15° C. had all moved towards the shore, while water of 14° C. had disappeared. At the same time the ship was carried in a north-easterly direction, as may be inferred from the positions at the beginning and end of St. WS 630, during which the ship was drifting for 12 hours (Fig. 9).

The question whether temperature changes on this line can be correlated with change of wind or with some cause due to the new locality into which the ship had drifted, may now be considered. In the first place it is to be noted that positions of isotherms had been

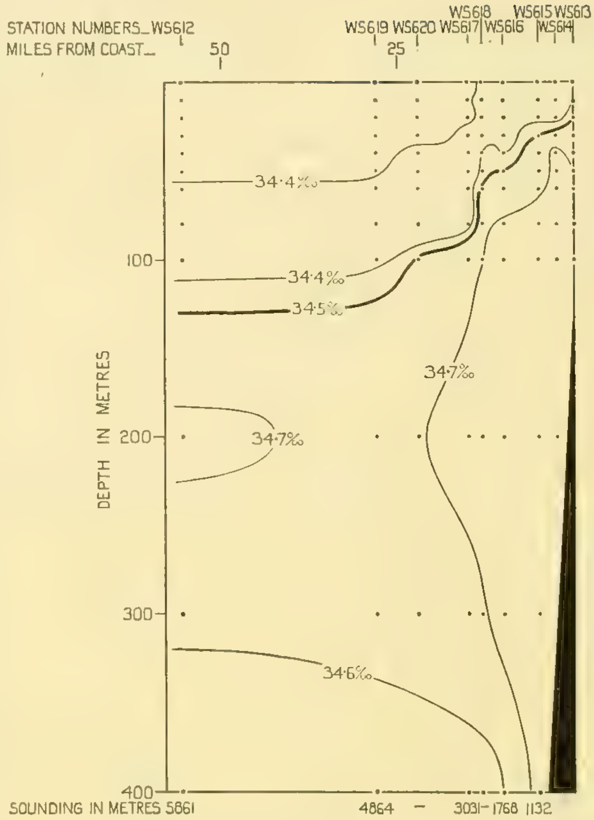

Fig. 22. Distribution of salinity. Section off Caldera, June 4–6.

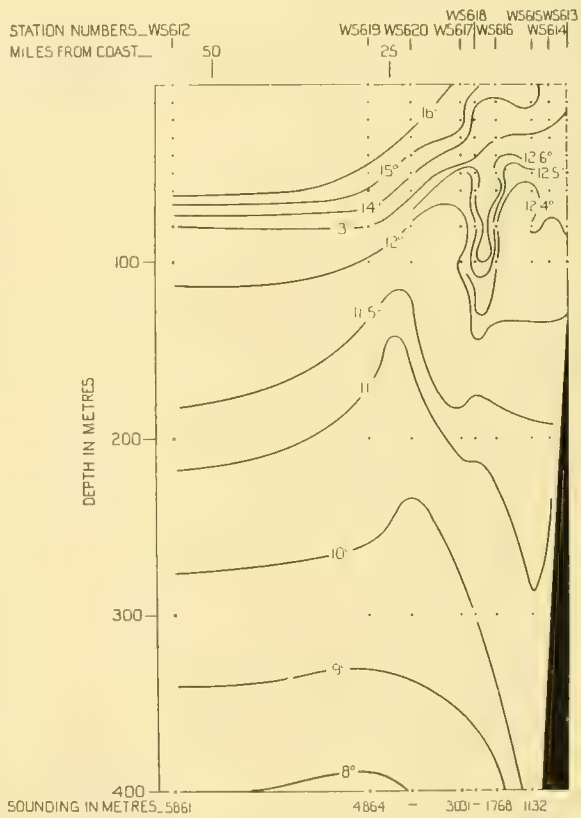

Fig. 23. Distribution of temperature (° C.). Section off Caldera, June 4–6.

The position of this section is shown in Figs. 3 and 5.

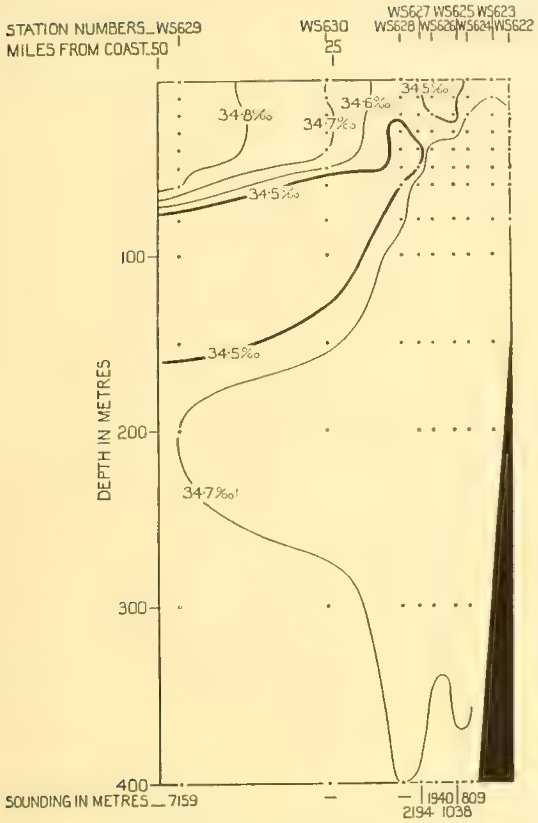

Fig. 24. Distribution of salinity. Section off Antofagasta on the outward journey, June 8–9.

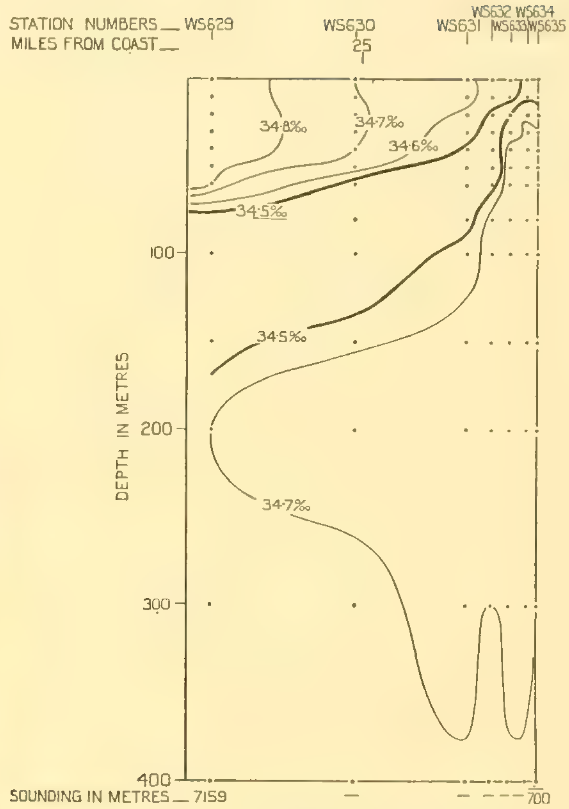

Fig. 25. Distribution of salinity. Section off Antofagasta on the return journey, June 9–10.

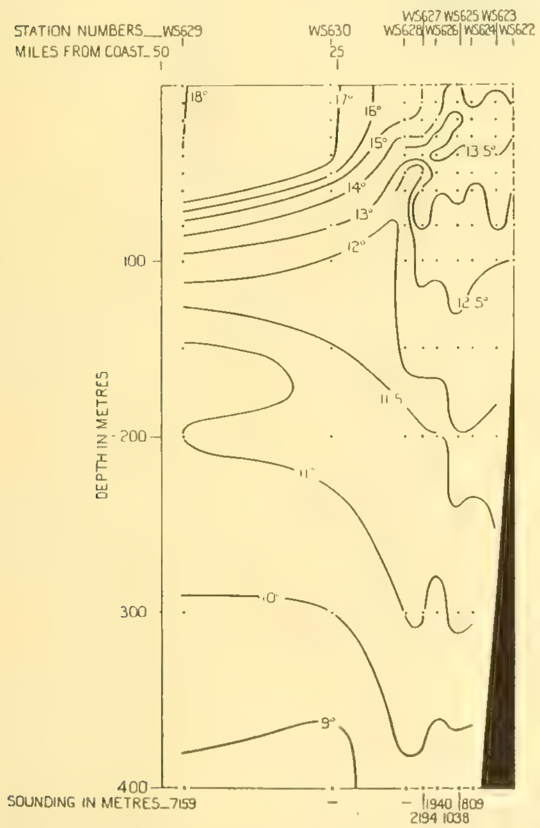

Fig. 26. Distribution of temperature (° C.). Section off Antofagasta on the outward journey, June 8–9.

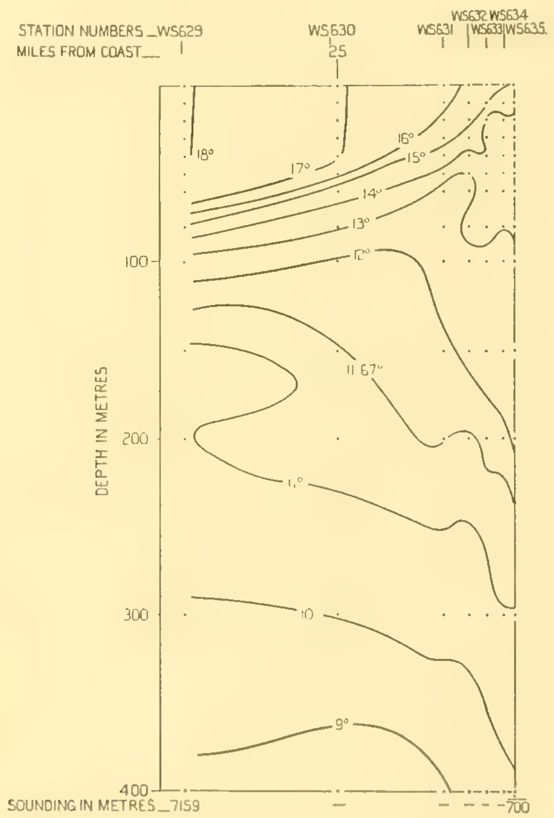

Fig. 27. Distribution of temperature (° C.). Section off Antofagasta on the return journey, June 9–10.

The position of these lines is shown in Figs. 3 and 9.

undergoing alteration before reversal of the wind: secondly, after the wind had changed to a north-easterly direction and to force 2, the ship continued to drift in its face to the north-eastward (from Sts. WS 630 to 632). If wind direction alone were to be considered these facts would argue against the wind being a controlling factor; but the strength of the wind is equally important, and the conditions here probably illustrate its influence exceptionally well.

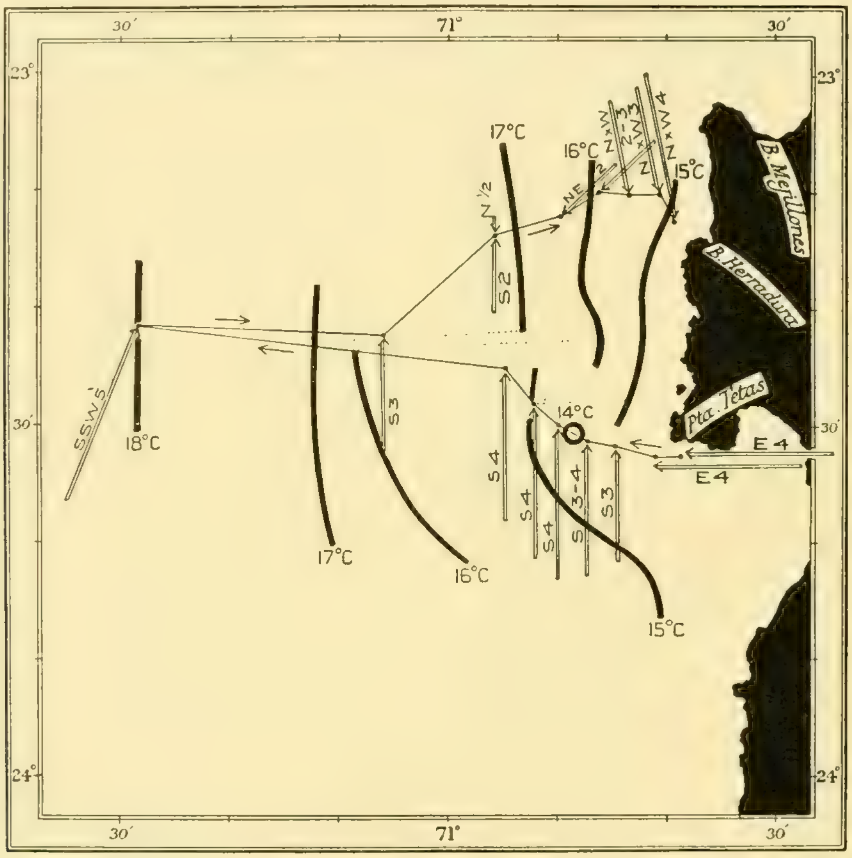

Fig. 28. Changes in wind and in the distribution of surface isotherms off Antofagasta in the period June 8–10, 1931. The sequence of events described in the text may be traced by following the track of the ship (thin line in direction of thin arrows) from Punta Tetas. The position of stations on this line is shown by dots (cf. Fig. 9). Isotherms are indicated by heavy lines, wind direction and force by broad arrows. The dotted lines show the shift of the isotherms of 15, 16 and 17° C.; the isotherm of 14° C. had disappeared when the site occupied by it on June 8 was revisited on June 10 (see Table III, and compare with Figs. 24–27).

Comparison of Figs. 26 and 27 shows far more active upwelling and far more cold water at the surface in section 26 of the outward journey than in 27 on the return. The wind data show a similar contrast of strong southerly and easterly winds on the westward journey and weak northerly winds during the return (Fig. 28). While the subsequent rise in surface temperature with change of wind might have been brought about by mixture of the upwelled with offshore water, the evidence of the ship's drift raises another possibility. We may picture the lighter warm surface water driven away from the coast as a result of these strong southerly and easterly winds acting in conjunction

with the deflecting force of the earth's rotation, and so drawing up to the surface a mass of heavy cold water from below. It becomes a system charged with potential energy.[1] We may imagine the ship taking observations on the outward journey at the height of this process, and that her drift was in the path of the deflected waters. But as soon as the wind force relaxes from force 5 to 3–2, as it did after St. WS 629, the deflecting force and so the pull of the warm offshore water is also relaxed, the cool inshore waters subside, and eventually the former warm surface waters flow back, and we have the conditions met on the return journey. In this way the north-easterly drift of the ship from Sts. WS 630–632 on her return journey, might indicate the influence of the returning waters. The displacement of the surface isotherms with the changing wind conditions is illustrated in Table II. The first section (Fig. 26) may illustrate upwelling and the second (Fig. 27) subsidence.[2] The question is discussed further on pp. 206, 208 and 213.

Table III. *Change in position of surface isotherms off Antofagasta*

	Position of isotherms (miles from the coast)		Displacement of isotherms (miles)
	June 8, 9	June 9, 10	
14° C.	8	—	—
15° C.	12	2	10
16° C.	28	10	18
17° C.	30	15	15
18° C.	46	46	0
Wind: Direction	S 4° E	N 1° E	
Force, m.p.h.	12·7	6·1	

With a change in the wind from south to north, the isotherms of 15, 16 and 17° C. shifted towards the shore.

In the Bight of Arica it was interesting that a strong inshore current and upwelling should occur in the absence of any wind. The weather was calm and the high temperature of 19·1° C. was found unexpectedly close to the coast, a well-marked thermocline existing close to the surface. The absence of any sign of an earlier disturbance suggests that upwelling was probably at its height. The possibility that these high temperatures were related to a wedge of warm highly saline water off Peru is suggested in Figs. 16 and 17, and that they might have been due to a counter-current is discussed on pp. 192–3.

[1] Sandström uses the term "Archimedean forces".

[2] The possible influence of the land contour upon the extent of upwelling and consequently upon the amount of cold water to be found inshore, and the possibility that the water mass off Baia Herradura is of different origin to that off Punta Tetas should not be lost sight of; they are discussed on p. 208.

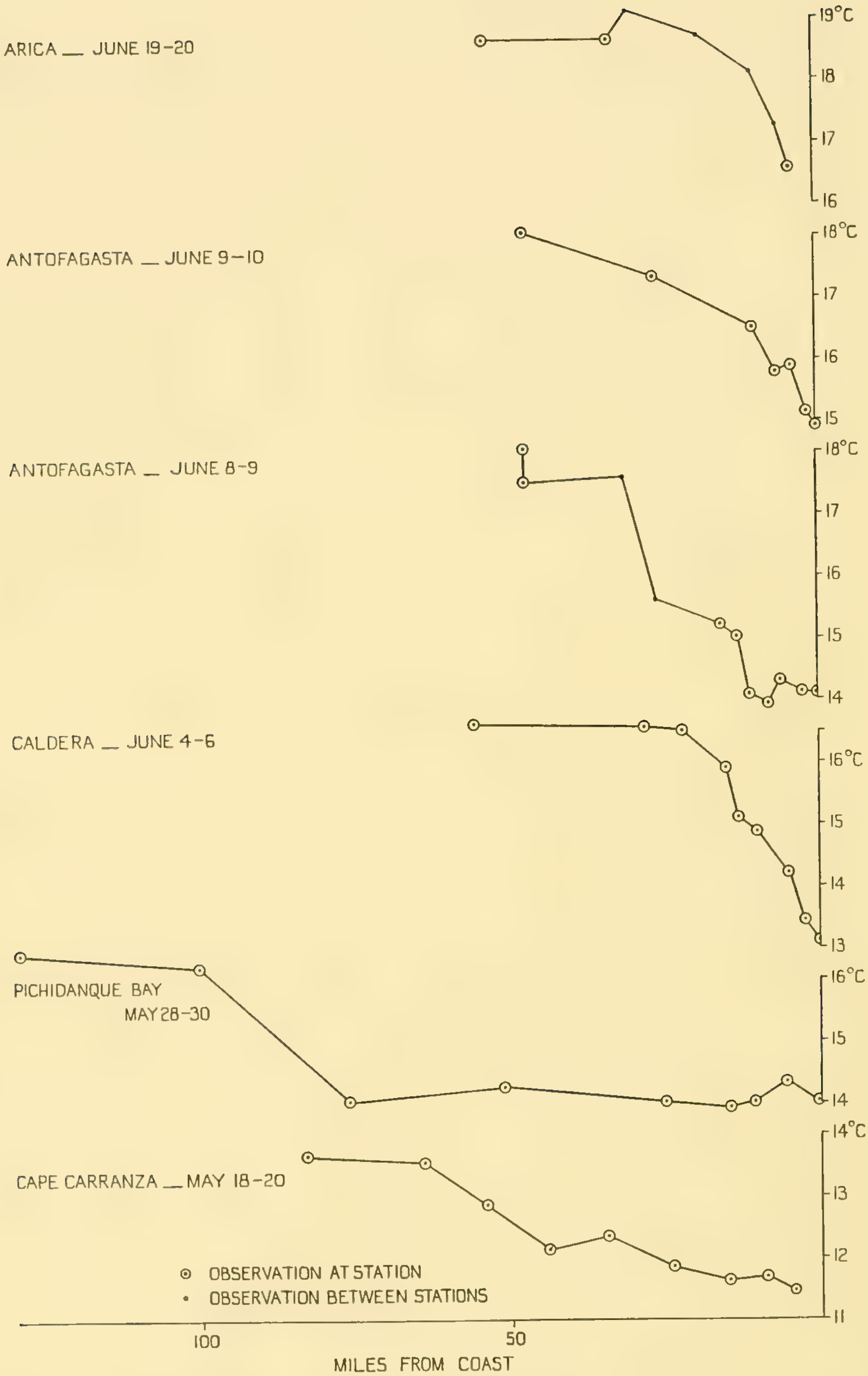

Fig. 29. Curves illustrating the surface temperature across the current, along lines placed normal to the Chilean coast.

Note to Fig. 30. The temperature values plotted in the curve Guañape Islands, July 10–11 should be read as one degree lower than those shown on the scale: the curve includes data collected off Salaverry at Sts. WS 675 and 676.

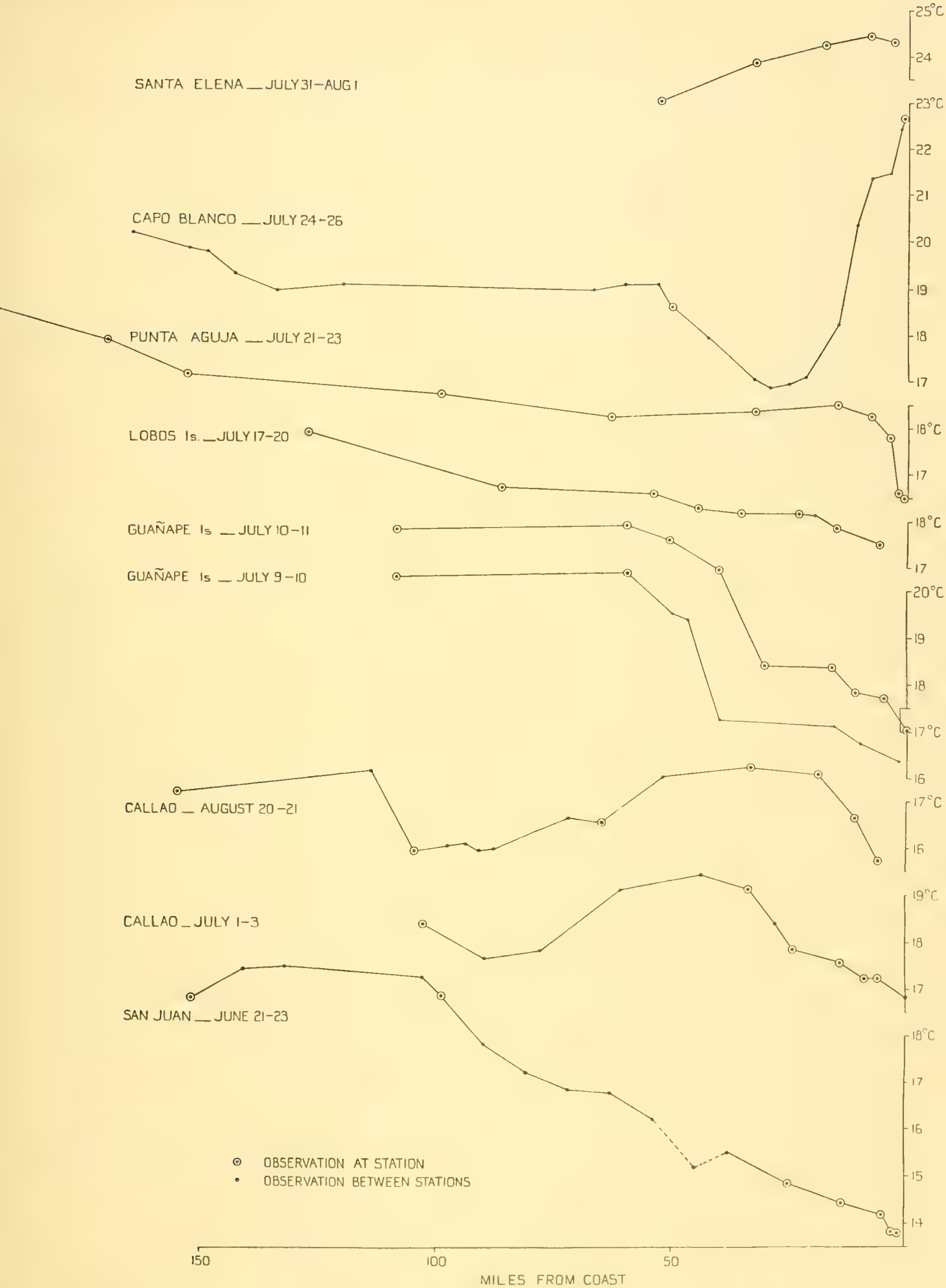

Fig. 30. Curves illustrating the surface temperature across the current, along lines placed normal to the Peru and Ecuador coasts.

18–12° S: SAN JUAN AND CALLAO

The meteorological and hydrological conditions off San Juan and Callao present an interesting contrast with one another and with those off Arica (compare Figs. 4 and 16 and also 31–33). At Arica in calm wind-free conditions, surface isotherms were bunched close to the coast, yet upwelling and northerly current were strong inshore. Off San Juan a strong south-east wind blew and upwelling was such that the surface isotherms spread out from the coast. Off Callao the wind lay towards the shore, with a slackening of upwelling and with the surface isotherms again bunched close to the shore.[1]

Off San Juan the volume of cool water was greater than at any region hitherto examined. Upwelling phenomena were evidently at their height, and the temperature rose from 13·79 to 19·25° C. at 95 miles offshore. Beyond this the ship crossed a patch of water, warmer than the sea on either side, and which appeared to differ from the surrounding water in its movement (see p. 129). It was some 50 miles wide and had a maximum temperature of about 19·48° C. A warm wedge of very similar water was met later off Callao where it was also about the same width but closer to the coast; here its direction of movement was not noted. Northwards of Callao the wedge was traced to the Guañape Islands and possibly beyond, and later in the season it was again identified off Callao (see p. 171). Its appearance in section is seen in Figs. 32, 33 and 52.

The absence of current at Callao, the onshore wind and the closing of surface isotherms with the coast, indicate that the temperature section illustrated in Fig. 32 may be a record of subsidence and not of an upwelling of cool water. This conclusion receives further support from observations of a seasonal character given on pp. 169–171, Fig. 51.

These features are illustrated in the curves of surface temperature along the path of the current (Fig. 34). Curves illus-

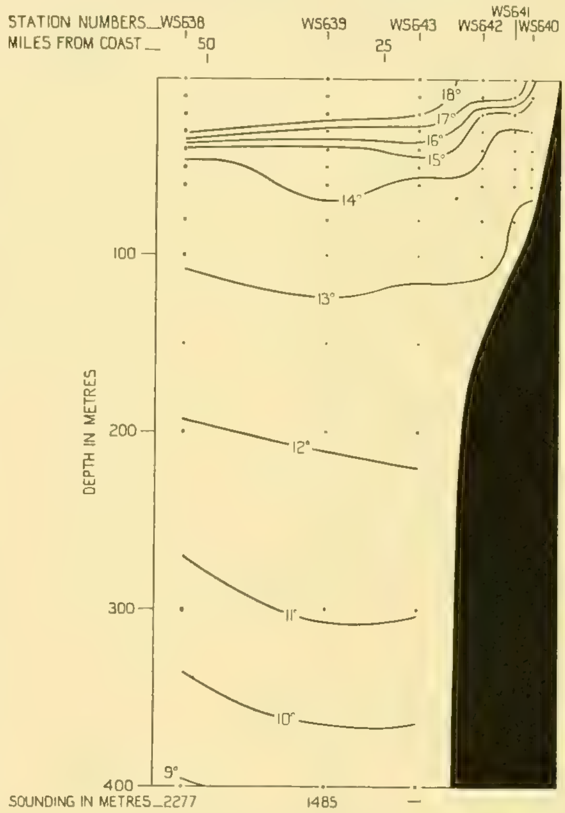

Fig. 31. Distribution of temperature (° C.). Section off Arica, June 19–20. The position of this section is shown in Figs. 3 and 11; the corresponding salinity section, in Fig. 43.

[1] It should be understood that in this account the observations are presented in chronological order and that the hydrological conditions are therefore traced from south to north. To avoid inconsistency in treating the subject as a whole, it is necessary, also, to trace counter-currents against their direction of flow. The reader is asked to bear this in mind, particularly in the description of the warm wedge; conclusions on its nature will be drawn after the evidence of salinity and of other data has been considered.

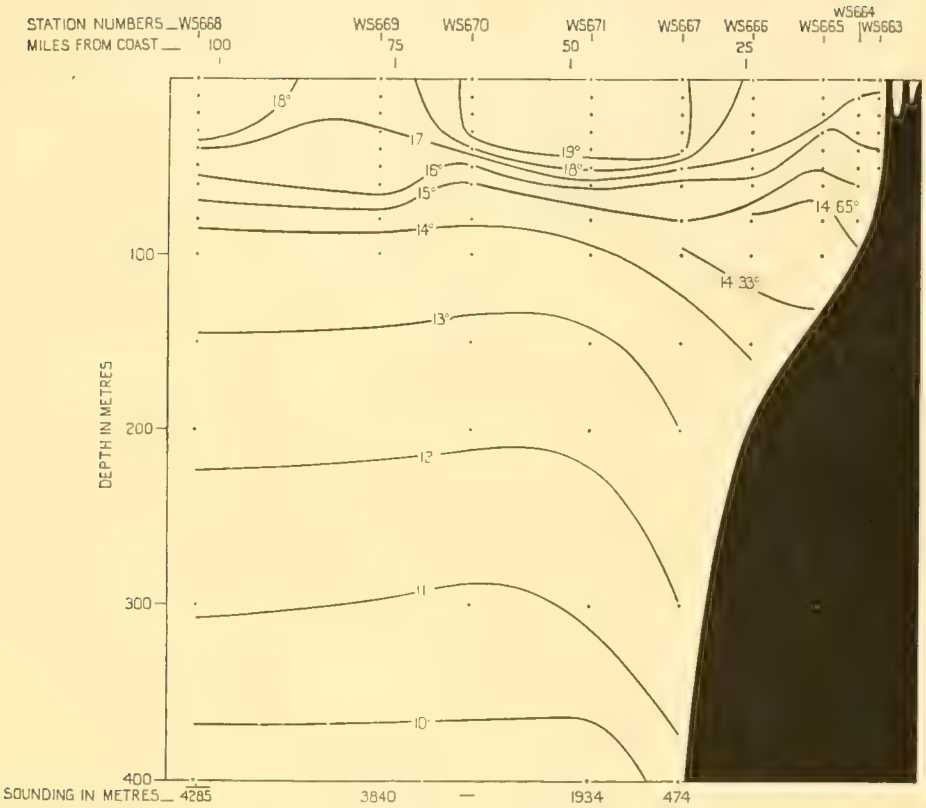

Fig. 32. Distribution of temperature (° C.). Section off Callao, July 1–3. The position of this section is shown in Figs. 2 and 10.

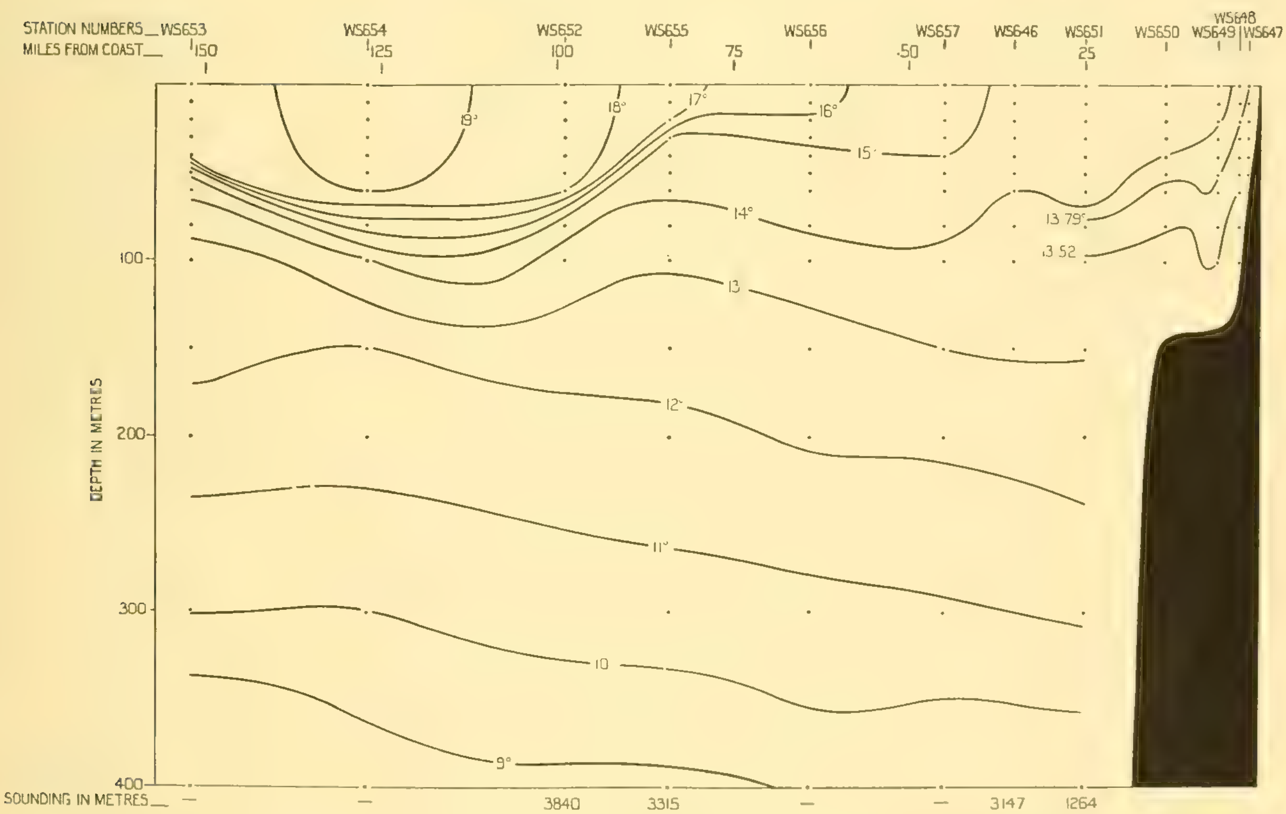

Fig. 33. Distribution of temperature (° C.). Section off San Juan, June 22–24. The position of this section is shown in Figs. 2 and 11.

Salinity sections corresponding to the Figures on this page are illustrated on p. 165

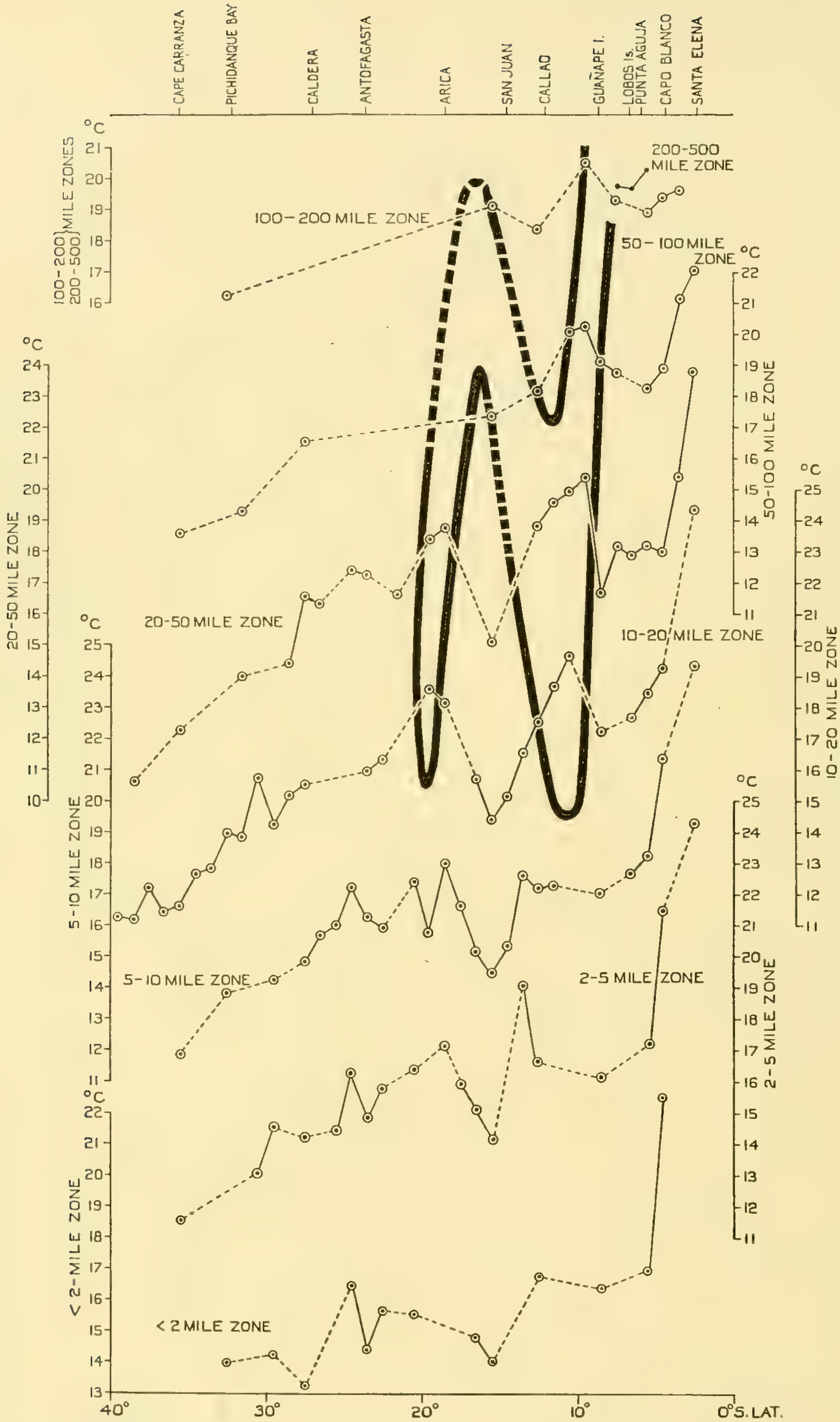

Fig. 34. Curves illustrating the mean surface temperature along the path of the current. Each curve represents the temperature of a zone at a given distance from the shore, the data within it being averaged separately for each degree of latitude (Appendix VI). The curves are broken where data are wanting. Regions influenced by an inflow of warm oceanic water (*vide* warm wedge in text) are indicated by a heavy line.

trating the mean surface temperature of the inshore zones, at 2–5 miles and 5–10 miles, agree in showing a pronounced fall of temperature at Antofagasta and a recovery which reaches its peak at Arica; but within 2 miles of the coast water remains cool, and this is interesting since there is no wind. After Arica, where the coast alters direction and the winds had increased very considerably, the water within 5, 10 and even 50 miles of the shore was found to be cooler than it had been since the latitude of Coquimbo. From San Juan to Callao another rise in temperature was taking place, and this is where wind was blowing across the usual direction and towards the shore (Fig. 4); the isotherms ran closer to the coast, the cooler water having disappeared (Fig. 16).

In the offshore zones, the curves for 10–20 miles, 20–50 miles, 50–100 miles and 100–200 miles, come under the influence of the warm-water wedge which is picked out in Fig. 34 by heavy lines. Off Arica its influence is shown in the zones 10–20 miles and 20–50 miles, but lack of observations farther out makes its seaward boundary doubtful. Off San Juan its influence is shown by the two outermost curves only. Off Callao, where the warm-water wedge is close in, the curves for the 10–20-mile and the 20–50-mile zones are affected and a big rise of temperature is shown, whereas at greater distances from the coast the water is cooler. Northwards of Callao the wedge comes from the open sea and a sharp drop occurs in the 10–20-mile and in the 20–50-mile curves and even in the 50–100-mile curve which continues to drop as it enters more northerly latitudes. The N-shaped appearance of the warm-water wedge in this figure is of course given by the arbitrary arrangement of the curves and by the latitude scale having been compressed.

12°–5° S: GUAÑAPE ISLANDS, LOBOS ISLANDS AND PUNTA AGUJA

In the month of July 8 to August 7, the ship made four traverses of this region; once to Salaverry and back to Callao, and once to the Ecuador coast and back: she was thus able to make a more detailed examination of the current in this region than southwards of Callao (Fig. 2).

Northwards of Callao the spreading out tendency of surface isotherms is again in full play and winds are consistently south east. It is most noticeable in the warm-water wedge[1] which first gains in width and then slants away from the coast to a distance of over a hundred miles. In consequence, the lines of stations off the Guañape Islands, Lobos Islands and Punta Aguja from 107 to 204 miles in length, all fail to span it (Fig. 30). The shift seawards of the warm-water wedge has already been noted above in the curves of mean temperature (Fig. 34). At the same time the wedge loses definition. As it leaves the coast, the inshore waters become more and more homogeneous and the wedge less easily discerned. Whereas off Callao and the Guañape Islands its inshore margin was distinguished by a sudden change of temperature, farther to the north the surface temperature undergoes no sudden change (cf. the gradual rise off the Lobos Islands and Punta Aguja, Fig. 30). This increasing homo-

[1] See footnote on p. 148.

geneity is shown in both temperature and salinity in the upper 200 m. at these four localities (compare Figs. 32 and 36–38 with Figs. 44 and 46–48), and is probably attributable to progressive vertical mixture resulting from increased current off northern Peru. Thus the Peru Coastal Current gains immensely in breadth towards its northern end.

As the latitude of this section of the coast is lower than those previously examined, there is a natural rise in the general level of the surface temperature and salinity. A surface temperature of 16·00° C., that off Salaverry, is the lowest inshore temperature recorded in this region: in the wedge of warm water the temperature reaches 20·60° C.

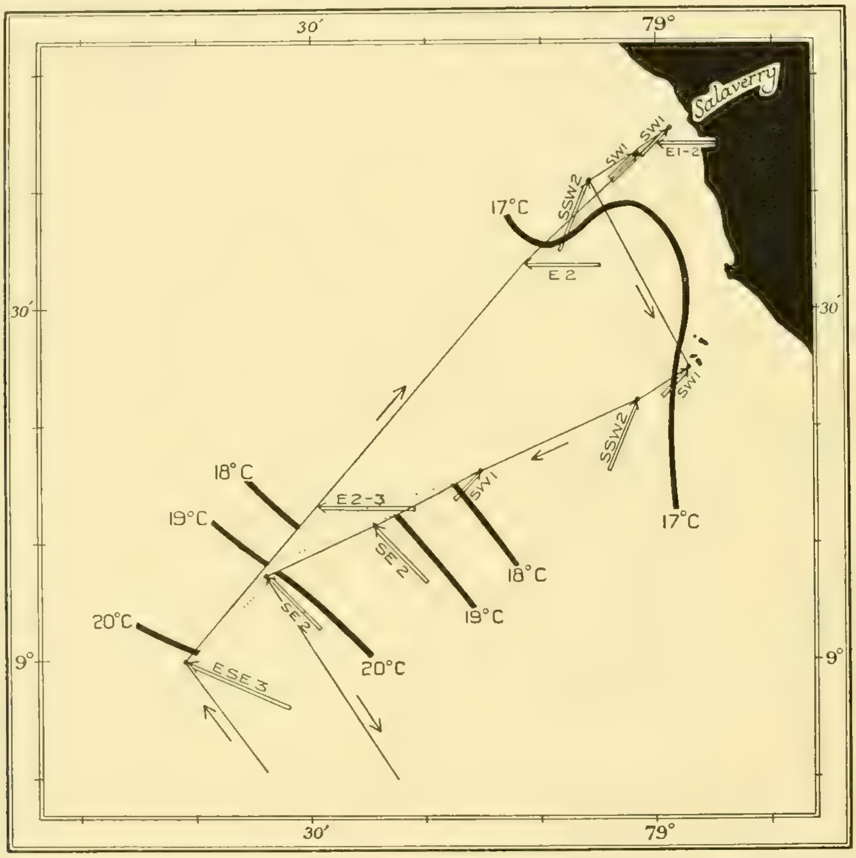

Fig. 35. Changes in wind and in the distribution of surface isotherms off the Guañape Islands in the period July 9–11, 1931. Symbols as in Fig. 28. Station positions may be identified by collation with Fig. 13. The dotted lines show the shift of the isotherms of 18, 19 and 20° C. (see Table IV).

The region of the Guañape Islands and Salaverry was examined in two states of the wind within a very short time (Fig. 35). In the evening of July 9, St. WS 674 was worked at 56 miles from land in winds of S 35° E with force 1–3 to 5–8 m.p.h. From this position the ship ran to Salaverry during the night, taking a record of surface temperature as she went (Table IV and Fig. 30). On the following night the ship worked a line of stations outwards from the Guañape Islands back towards the position of St. WS 674. In the meantime the wind direction had changed from south-south-east to south-south-west with force 1–2 m.p.h., and all isotherms at 20 miles to sea and upwards were now found closer inshore. The greatest displacement was over the middle of the shelf some 30 miles

from shore: here the 18° C. isotherm was 12 miles closer to land on the return outward than on the shoreward run: and at 50 miles the 20° C. isotherm had shifted shorewards about 9 miles. There seems to be no reason for thinking that this apparent change in the position of surface isotherms is due to an error in the ship's position and the synchronous change in wind suggests as more likely that the latter is related to the former as cause and effect (cf. conditions at Antofagasta). The question whether the section in Fig. 38 represents a process of subsidence after upwelling rather than a state of incipient active upwelling, is examined on pp. 208–9 and 213.

Since the ship was prevented from taking observations at less than 7 miles from the shore by the position of the Guañape Islands, three additional stations were worked in Salaverry Roads for the purpose of examining inshore conditions. Here a temperature of 16° C. was recorded at 5 miles from the shore (Appendix IV), and since it was recorded very soon after the change of wind from east to south-west, it may be conjectured that this is a legacy of the former strong wind rather than a consequence of the weaker.

Table IV. *Change in position of surface isotherms off the Guañape Islands*

	Position of isotherms miles from the coast		Displacement of isotherms miles
	July 9, 10	July 10, 11	
20° C.	55	46	9
19° C.	46	34	11
18° C.	42	29	12
17° C.	14·5	8·5	6
16° C.	—	5	—
Wind: Direction	E and ESE	SW–SSW	
Force, m.p.h.	2–10	2–5	

With a change of wind from east to west the isotherms of 17, 18, 19 and 20° C. shifted towards the shore.

The lines off the Lobos Islands and off Punta Aguja, situated comparatively close to one another, are similar in plan, illustrating the progressive widening of the Peru Coastal Current and the progressive homogeneity of the upper layers.

The better part of a week elapsed between completion of the Guañape Islands and commencement of the Lobos Islands line, the work being interrupted by a visit to Callao. The dangers of heavy drift around the rocky isles Lobos de Tierra and Lobos de Afuera precluded the usual course of letting the ship drift before wind and current: also an endeavour was made to examine the effects of these rocks upon the hydrological conditions. Accordingly courses were shaped, first to take observations off the exposed (south and south-east) aspects of the Lobos de Afuera, and then to place stations along a line midway between the latter and the Lobos de Tierra.

Compared with other lines, upwelling off the Lobos Islands seems in abeyance and the surface layer is comparatively warm, a value of 17·38° C. being the warmest inshore temperature met. This layer is also seen in Fig. 47 to be more saline than the surrounding water. Such a distribution of warm saline water leading to a slackening of

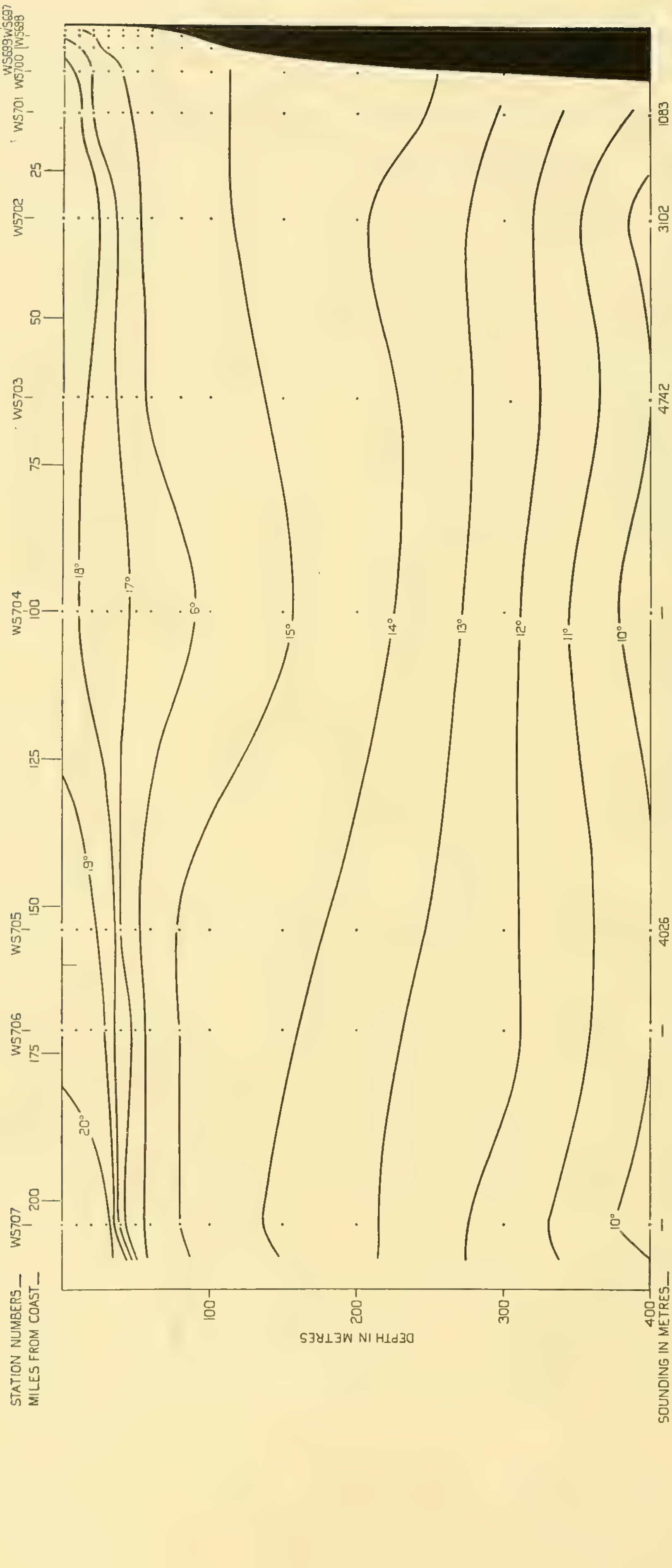

Fig. 36. Distribution of temperature (° C.). Section off Punta Aguja, July 21–23. The position of this section is shown in Figs. 2 and 12; the corresponding salinity section, in Fig. 46.

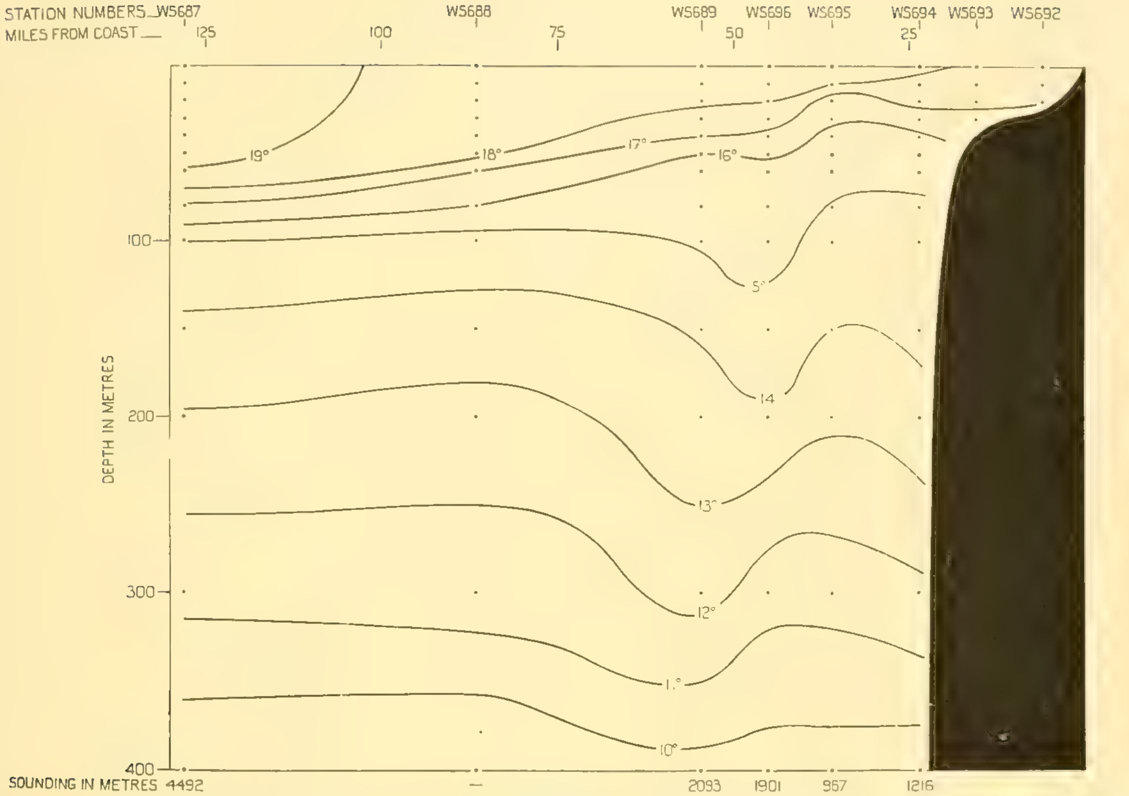

Fig. 37. Distribution of temperature (° C.). Section off the Lobos Islands, July 17–20. The position of this section is shown in Figs. 2 and 12.

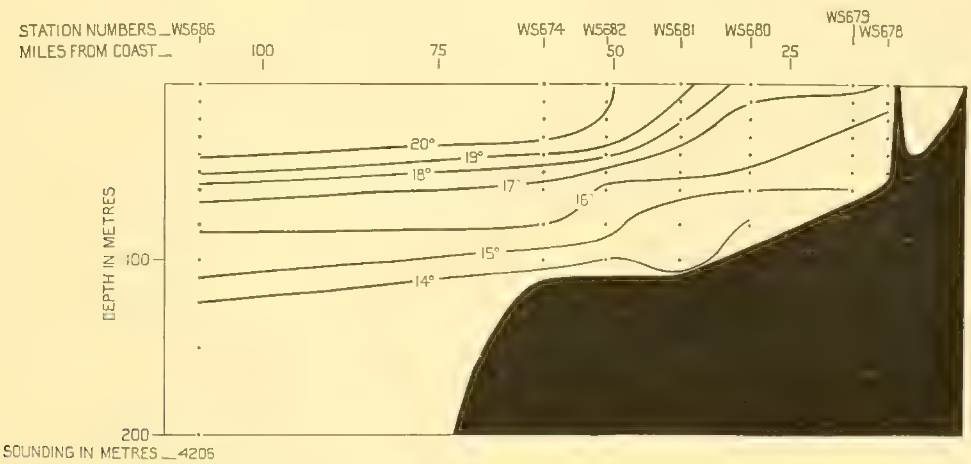

Fig. 38. Distribution of temperature (° C.). Section off the Guañape Islands, July 10–11. The position of this section is shown in Figs. 2 and 13.

Salinity sections corresponding to the Figures on this page, are illustrated on p. 167.

upwelling would be brought into being either by a counter-current or an eddy, the existence of which is rendered likely by the evidence of set and drift which was erratic in this neighbourhood, a current of 24 miles a day setting directly towards the shore (north-east by north) between Sts. WS 689 and 690. The influence of these conditions on the fauna and flora are discussed on p. 220, the possible influence of the rocks on upwelling on pp. 205 and 207.

Although pronounced upwelling brought cold water to the surface within 15 miles of Punta Aguja, yet over the next 189 miles the temperature rose no more than 2·2° C. Thus immense breadth is a conspicuous feature of the northern part of the Peru Coastal Current. The warm-water wedge seems to be recognizable though relatively less warm; its western margin (the isotherm of 20° C.) ragged, irregular, and ill-defined off Punta Aguja leaves the area investigated. The eastern, shoreward margin of the wedge, swerving outwards from the shore, is found at a distance of 50 miles off the Guañape Islands, 140 miles off the Lobos Islands and 180 miles off Punta Aguja (Fig. 16).

5–2° S: CAPO BLANCO AND SANTA ELENA

Here the current leaves the coast on its entry into the tract leading to the westerly flowing South Equatorial Current. We are concerned with its point of convergence with the warm waters off Ecuador. Although the hydrology of the complex region outside the Peru Current is beyond this enquiry, the following notes derived from Schott's valuable paper (1931) will assist in the interpretation of conditions near the coast.

Cool water of moderately high salinity (>35 ‰) is brought into the region from the south by a chain of processes constituting the Peru Coastal Current, and it is drawn off to the westward in the wake of the South Equatorial Current. North of this the Equatorial Counter-current flows eastwards in the opposite direction, and brings warm water of low salinity (<33 ‰) into the region from the west. The characteristics of these two currents are very different, and the coasts adjoining them differ from one another correspondingly. The warm counter-current, whose salinity has been lowered by tropical showers, flows against Ecuador, and the country has luxuriant forests drenched by rains. The Peru Current has acquired its higher salinity through the drying action of the south-east trades and the Peruvian coast along which they blow is a desert region. Similarly the Cocos Islands in the path of the counter-current have tropical scenery, whereas the Galapagos Islands in the South Equatorial Current has a much more scanty vegetation.[1] But it is not clear from Schott's account whether the relation of current to climate in the one is the same as that in the other. In the first

[1] The appearance of the Galapagos vegetation varies. Darwin (1845) remarks that "Nothing could be less inviting than the first appearance. A broken field of black basaltic lava thrown into the most rugged waves, and crossed by great fissures, is everywhere covered by a stunted sunburnt brushwood which shows little signs of life." Agassiz (1891), on the other hand, writes: "Arriving as we did at the Galapagos at the beginning of a remarkably early rainy season, I could not help contrasting the green appearance of the slopes of the islands, covered as they were by a comparatively thick growth of bushes, shrubs, and trees, with the description given of them by Darwin who represents them in the height of the dry season as the supreme expression of desolation and barrenness." The climate of the islands must depend upon the position of the convergence between the counter-current and the South Equatorial Current.

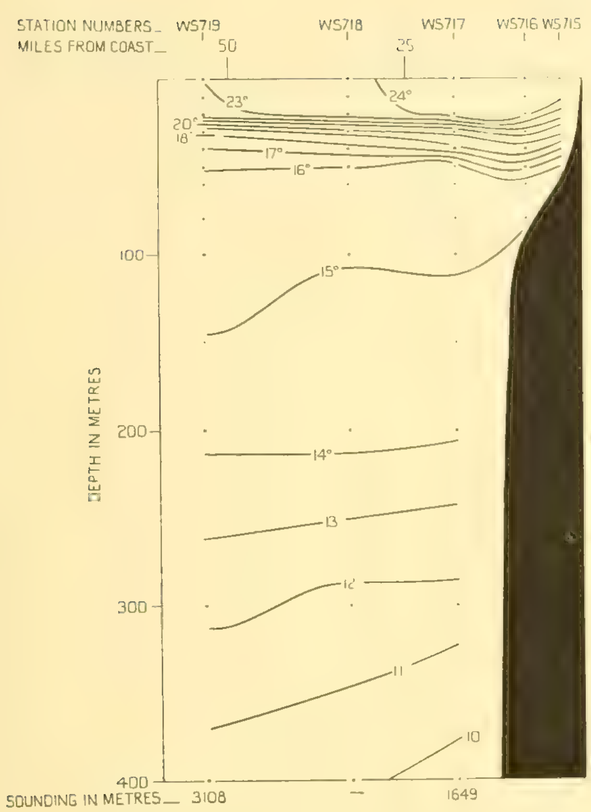

Fig. 39. Distribution of temperature (° C.). Section off Santa Elena, July 31–August 1.

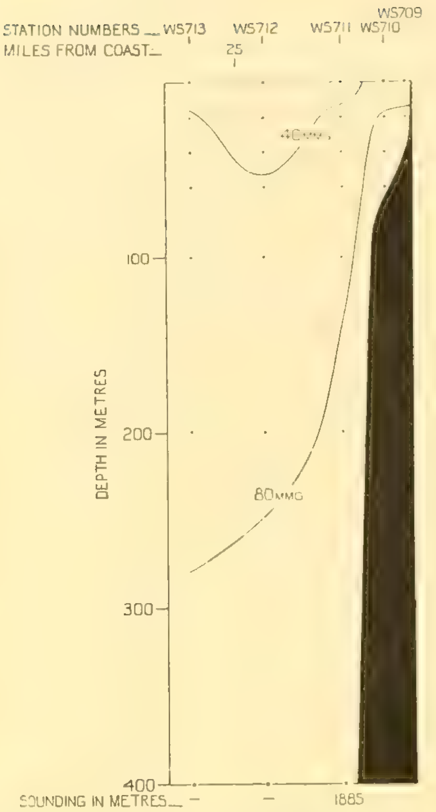

Fig. 40. Distribution of phosphate (per m.³). Section off Capo Blanco, July 24–26.

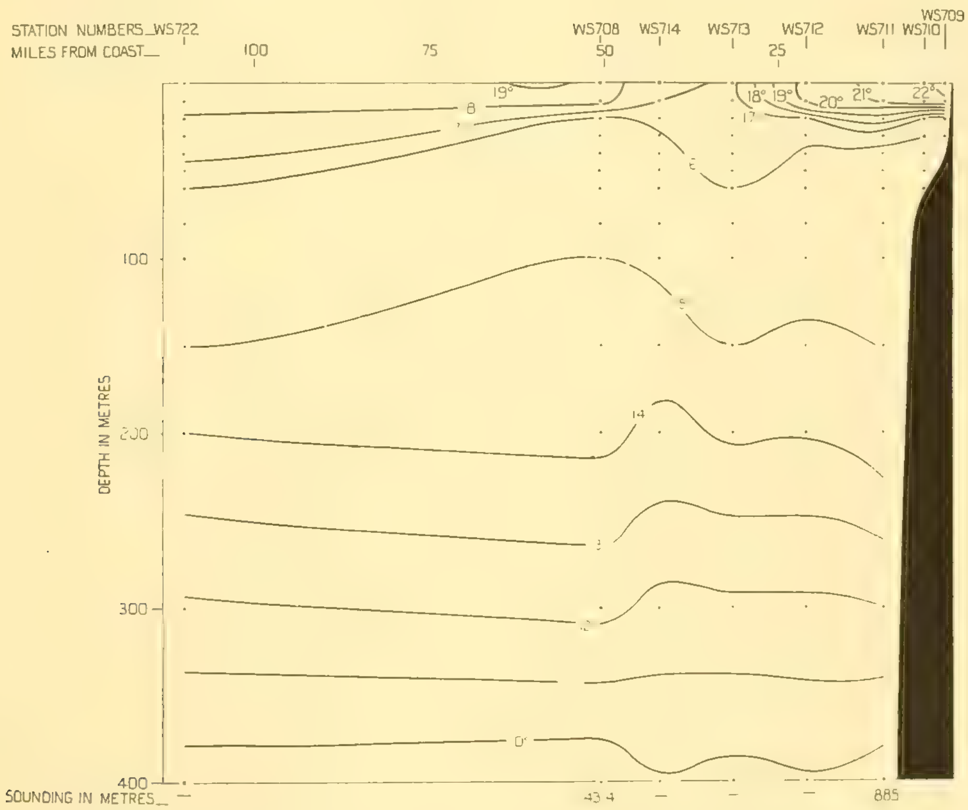

Fig. 41. Distribution of temperature (° C.). Section off Capo Blanco, July 24–26.

The positions of the sections on this page are shown in Figs. 2, 70 and 71; the corresponding salinity sections, on pp. 169 and 168.

the counter-current is accessory to the cause of humid winds, tropical showers and its own low salinity, while in the second, drying winds are the cause both of the coastal deserts and the high salinity of the Peru Current (see p. 229).

Along the line of contact where the two currents converge, water movement gives rise to extensive mixture. The triangular area of the Guayaquil-Galapagos-Panama region is one of irregular currents and complex eddies. Water movements on a much vaster scale result from variation in one or other of the controlling forces that lie outside this province: thus failure of the trade wind or preponderance of the northerly will cause a phenomenon like *El Niño*. The boundary between hot and cold water possibly affords a delicate indication of the balance between factors remote from the area itself.

At the time of our visit the convergence of the cool Peru water and the warm water from Ecuador, occurred off Capo Blanco: it followed an irregular S-shaped line within 50 miles of the coast, and here the isotherms lay close together. The convergence line then pursued a north-west direction and was less defined (Figs. 16, 70 and 71).

The sections across this region illustrate clearly the relation to one another of the waters of different temperature (Figs. 36 and 39–41): that off Punta Aguja is typical of sections south of this line in which cooler water is brought to the surface by upwelling. The next section cuts across a tongue of hot water off Capo Blanco. The hot water was scarcely 20 m. deep, lay over the cooler Peru Current and extended about 25 miles from the coast; its temperature ranged from 19 to 22° C. The Peru Current beneath sustained a local rise in temperature, but in other respects the section resembles those already examined. Thus the 17° C. isotherm occurred at the surface although as far out as 35 miles offshore beyond the hot-water tongue. A small patch of water of 19° C. at 55–65 miles from shore, like the hot-water tongue, was a sign that the northern boundary of the Peru Current was near.

Off Santa Elena, transformation of conditions was more complete. Hot water of 24·43° C. occupied the surface close inshore, and proceeding out to sea the temperature fell instead of rising as it is wont to do off Chile and Peru (Figs. 29 and 30). At 50 miles offshore the temperature was 23° C., a drop of 1·4° C., but the hot water probably extends westwards a considerable distance before it comes into direct contact with the cool Peru Current. Although this section is the converse of those we have been describing, upwelling seemed not altogether absent; it seemed to be held in check by a thermocline at 20–56 m. In this layer the temperature dropped from 24 to 16° C., and it is possible that such a layer of hot water might lie on the surface like a blanket and effectually check vertical mixing even in conditions otherwise conducive to upwelling (cf. conditions at Capo Blanco and conditions in the Gulf of Panama, p. 206).

The surface temperature of the area just considered is illustrated in Fig. 34 in which the mean changes in zones at varying distances from the shore can be traced from south to north. We have seen in the preceding pages that wherever the warm-water wedge encroaches upon these zones the mean temperature undergoes a sharp rise. This rise is shown in Fig. 34 by thickened lines. The curves also show the sudden increase in surface temperature as they leave the Peru Current and enter upon equatorial water in the Gulf of Guayaquil. They show too that the contrast is greatest close inshore when they leave the upwelling region of Peru and enter the high temperatures off the Ecuador coast,

illustrating the principle already noted that inshore temperatures in the Peru Current are cooler than those offshore, while north of the Peru Current inshore temperatures are warmer than those offshore. The curve at 10–20 miles offshore shows by its progressive warming from 8 to 4° S that the influence of coastal upwelling is less and that the influence of equatorial water is not much felt south of Capo Blanco. The water in the zone 50–100 miles offshore does not show great warmth off Ecuador; its salinity between 2 and 3° S suggests a mixture of the Peru and tropical waters. The curve for greater distances (100–200 miles) has no appreciable temperature rise and indicates that the water is of more purely Peruvian origin.

SALINITY

In the preceding section, the cool water at the surface inshore has been shown to be derived from lower layers by upwelling, and in certain localities the distribution of surface isotherms suggest horizontal movement also. But the origin of the water masses participating in this circulation is less easily seen in distribution of temperature because of the regularity of thermal stratification in the deeper water. At the surface, on the other hand, salinity is a less straightforward guide than temperature because it is liable to be altered by precipitation or evaporation. Thus in the south of the region the surface water is diluted by rains of the temperate zone and offshore is less saline than water at a depth of 160–200 m., whereas further north, as a result of the drying action of the south-east trades, the surface offshore is more saline than the lower layers. In consequence of this reversal of conditions and of upwelling near the coast, the Peru Coastal Current south of the subtropical convergence is more saline, and north of the convergence less saline than the surface of the ocean immediately adjacent.

Surface salinity in the southern part of the region is moderately low and is probably sub-Antarctic water. At the subtropical convergence in lat. 24–26° S (Fig. 42) it sinks beneath more saline but warmer subtropical water and continues northward beneath it as a subsurface current. The subtropical water at the surface has a depth of about 40 m. and continues northwards at the surface until it meets with the still warmer less saline Equatorial Counter-current. The convergence of these two water masses is recognized as the northern boundary of the Peru Current, but the section in Fig. 42 indicates that the latter extends some way northwards beneath the counter-current. Beneath these water masses is situated the Antarctic intermediate water whose low salinity is derived mainly from molten ice.

The origin of water masses in the South Atlantic Ocean corresponding to these four has already been described (Deacon, 1933), but their behaviour in the eastern South Pacific is modified by the peculiar conditions obtaining on the west coast.

The section illustrated in Fig. 42, which is approximately meridianal, does not cut the subtropical convergence sharply, but at the surface the isohalines of 34·40–34·90 are seen to be spread out between the parallels of 21 and 28° S. This shows that the convergence is not crossed at right angles, but that it curves northward near the coast in accordance with the general circulation. The inference receives ample confirmation from Sverdrup's results (1931). In his fig. 4 illustrating Sts. 50–60 in a north-west to

south-east direction the subtropical convergence is cut sharply; the isohalines of 34·40–34·90 ‰ being bunched between Sts. 55–57 in the positions given in Table V. In his fig. 6 illustrating Sts. 60–70 which lie south-west to north-east, the section is inclined to run along the convergence; the latter is in consequence not well defined, but the isohalines of 34·40–34·90 ‰ are spread out between Sts. 62 and 67, and the iso-

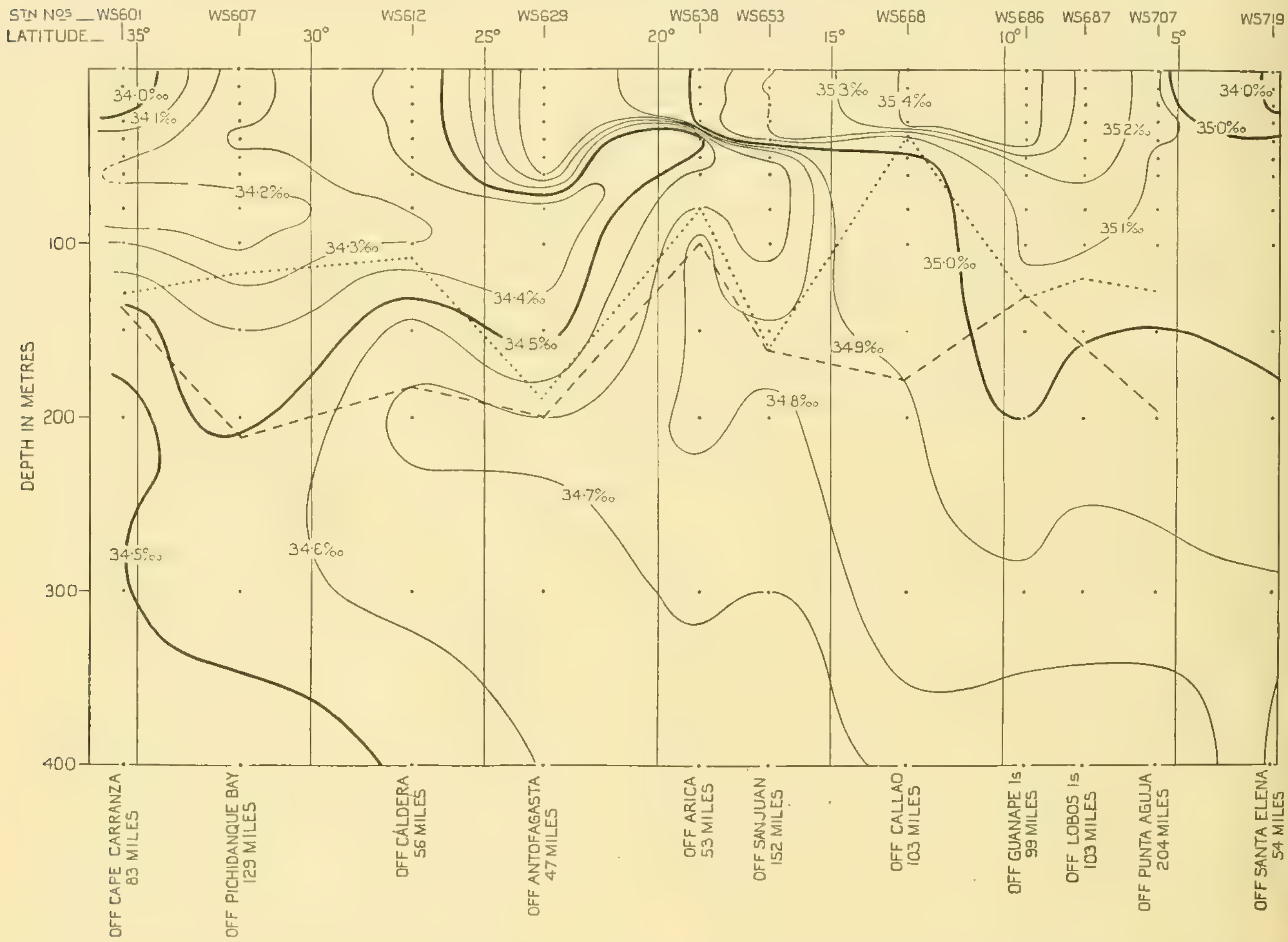

Fig. 42. Section illustrating the distribution of salinity in the upper 400 metres along the path of the current. The section runs roughly parallel to the coast and is situated at a mean distance of about 100 miles from it. The dotted line indicates the value of the surface salinity at the inshore station corresponding to each of the stations plotted; and the broken line indicates the maximum depth apparently affected by upwelling at each of these localities.

halines of 34·60 and 34·70 ‰ cross the section in three places. The positions occupied by the convergence in this section together with our own results are also given in the table, from which the convergence is seen to run east and west in the open ocean and to curve northwards on approaching the coast. The disposition of surface isohalines given by Schott shows a similar tendency. In the eastern South Atlantic, on the other hand, the subtropical convergence pursues an easterly course, and in 10° E is placed in lat. 37° 30′ S (Deacon, 1933, p. 211).

In consequence of this, the Peru Coastal Current crosses a convergence: and two

distinct water masses, the one sub-Antarctic, the other subtropical, contribute to its formation.

Table V. *Approximate position of the subtropical convergence in the eastern South Pacific*

	Latitude ° S	Longitude ° W
1928–29. 'Carnegie' Sts. 55–57	33	109
1928–29. 'Carnegie' Sts. 62–67	32 28	89 85
1931. Sts. WS 612–629	24–26	70–71

In the lower latitudes of the South Atlantic, Deacon recognizes a surface layer of high salinity (> 36·00 ‰) which he distinguishes as tropical water. A similar layer in the eastern South Pacific occupies an extensive area near the centre of anticyclonic circulation and was entered by the 'Carnegie' at about 1300–1400 miles from the South American coast. No water of such salinity was met within the Peru Coastal Current, but the salinity of the warm-water wedge was higher than that of water on either side.

In this connection a closer study of its salinity may be made; the depth at which the maximum salinity values were found on the five lines from the Lobos Islands to Arica being given in Table VI.

Table VI

St. WS ...	687	686	671	654	637
Lat. S	7° 42′	9° 25′	12° 10′	16° 36′	19° 48′
Salinity ‰	35·27	35·47	35·59	35·34	35·05
Depth m.	0	0	20	50	30

Salinity attains its highest value off Callao in about 12° S, declining towards north and south. In the northern part of the region, the wedge appears to the westward of our stations, and the salinity at St. WS 687 and to some extent St. WS 686 have been lowered by admixture with upwelled water. At the Guañape Islands (9° S), Callao (12° S) and San Juan (16° S), where the wedge was most developed, the maximum values show a progressive sinking in depth with increase of latitude. Identification of the wedge at Arica is not proven, but the maximum salinity values are well below the surface. According to these and temperature data, the origin of the wedge lies at the surface to the west of the area investigated: it may be a counter-current in the subtropical water, but it may perhaps be regarded as of tropical origin.

Two other peculiarities of these water-masses are noteworthy. The meridianal section in Fig. 42 shows that the sub-Antarctic water, after travelling at the surface as far as the subtropical convergence, sinks and then continues northward as a subsurface current for some 10° of latitude; whereas in the South Atlantic, after sinking at the convergence, the sub-Antarctic water returns southward almost immediately, in company with

a southerly return current of subtropical water at 80–200 m. (Deacon, 1933, pp. 207–10). Fig. 42 also shows a return current flowing southwards between the sub-Antarctic water and the Antarctic intermediate water. The origin of this return current is not very clear but seems to lie partly in sub-Antarctic water, partly in subtropical water, between 10–20° S. It does not seem to be homologous with the Atlantic return current, for it flows at a depth of 150–350 m. and will be shown in cross-section to be a coastal current; it is not in evidence in the oceanic sections run by the 'Carnegie'.

Thus, on the eastern fringe of the South Pacific, four principal water-masses enter into the circulation of the troposphere. At the surface, northerly flow is characteristic of the sub-Antarctic and the subtropical layers; and in the deep water, of the Antarctic intermediate layer. Southerly flow at the surface is found in the Equatorial Counter-current, and below the surface in a return current of subtropical water which penetrates between the surface layers above and the Antarctic intermediate water below.

Of these water-masses the sub-Antarctic and the subtropical water are the most important to the Coastal Current, because it is from these layers that the upwelling water is drawn. In lat. 32° S the sub-Antarctic water extends from the surface to a depth of about 150 m., and in this latitude the isohaline of 34·50 ‰ might be regarded as the boundary between it and the return current beneath. The isohaline of 34·40 ‰ distinguishes this in turn from the yet deeper Antarctic intermediate water. In lat. 2° S water of the Equatorial Counter-current having a salinity of less than 35·00 ‰ overlies the subtropical water which extends from about 40 to 600–700 m., and here the isohaline of 34·60 ‰ may be taken to represent its lower boundary.

CAPE CARRANZA

The salinity section off Cape Carranza illustrates upwelling in temperate latitudes, the saline return current rising up into less saline sub-Antarctic water at the surface (Fig. 18). The highly saline return current flowing southwards is depicted by the isohalines of 34·50 ‰, and it seems more than probable that this current is confined to the coastal region. One observation only, at 400 m. at 83 miles from land, represents Antarctic Intermediate water.

PICHIDANQUE BAY

Off Pichidanque Bay the highly saline layer is also depicted by the isohalines of 34·50 ‰, and here too it is drawn towards the surface by upwelling, but less so than at Cape Carranza, with the result that in sectional view (Fig. 20) the layer is seen to be more band-like. In it, the highest salinities were inshore: and in Fig. 21 the isotherms give some indication that this water was warmer than at corresponding depths in the open ocean. Although surface salinity inshore is still higher than offshore, the increase in oceanic values is a sign of the reversed conditions farther to the north. Pichidanque Bay is south of the convergence. The Antarctic intermediate water has now sunk lower than 400 m. and is not shown in this section. Upwelling occurs from 118 m., but layers as deep as 212 m. seem to be affected.

CALDERA

The sub-Antarctic water and the highly saline return current are easily recognized in Fig. 22. The observations off Caldera were only just south of the subtropical convergence, and the latter's influence is reflected in the surface salinity offshore which now has a value of almost 34·50 ‰. It is therefore higher offshore than inshore; a condition characteristic of the greater part of the Peru Coastal Current. As a result of upwelling the saline return current is drawn to within 40 m. of the surface; but if upwelling had been more active, the return current might have been drawn to the surface and the inshore waters would then have had the higher salinity.

ANTOFAGASTA

The rise of the highly saline return current to the surface suggests that Fig. 24 illustrates upwelling of unusual strength, yet the salinity offshore (St. WS 629) continues to be the higher; this is because the subtropical convergence was crossed in approximately lat. 24–26° S, and the outermost of the stations on this line lay on its northern edge. The sub-Antarctic water, formerly at the surface, is now below the subtropical water but apparently still flowing towards the north; below it the return current flows south. Figs. 23, 26 and 27 show that the temperature of the return current off Antofagasta and Caldera is distinctly higher than water of the open ocean.

If the inferences drawn on p. 142–5 are correct, the two sections illustrating salinity off Antofagasta indicate first such upwelling that the highly saline return current has been drawn to the surface inshore, and second that it has subsided beneath. In reaching the surface, the return current has mixed with the sub-Antarctic water, with the result that their salinities are modified; nevertheless the layers are clearly distinguishable. Within the return current, salinity is in its highest concentration close to the coast, and this distribution accords closely with the distribution of the layer off Cape Carranza where upwelling had also been vigorous, and supports the suggestion that the layer is restricted to the coastal region (cf. conditions off San Juan, p. 164). This is discussed further on p. 200.

ARICA

At Arica the return current did not reach the surface, but the arrangement of water layers is seen (Fig. 43) to resemble that of other sections. The sub-Antarctic water now having values of >34·50 ‰ is at the surface inshore, while subtropical surface water now reaches values of >35·00 ‰.

SAN JUAN

The concentration of surface salinity at San Juan is such that the sub-Antarctic water is becoming obliterated but is recognizable at 60–120 m. (Fig. 45). For 60 miles the inshore surface waters were occupied by the highly saline return current; beyond this came still more highly saline subtropical water. In this lay a wedge of even more saline water (>35·25 ‰) which may be identified with the warm-water wedge (see

Fig. 33) described on p. 134, and this may perhaps be tropical water and a counter-current (see pp. 161 and 129). The fact that in this section the values of $>34{\cdot}90\ ^{\circ}/_{\circ\circ}$ in the return current did not extend farther away from the land than 110 miles fit the deductions made in regard to lines of less length, that the return current is a coastal phenomenon.

CALLAO

Off Callao the sub-Antarctic water is scarcely recognizable as a distinct layer. Observations at a depth of 60–80 m. at Sts. WS 669, 670 and 671 show a layer where the salinity is rather less than the values on each side, and this together with the comparative homogeneity of water between 50 and 150 m. are the only signs of a depleted layer. The absence of easily distinguished water layers, together with the warm highly saline wedge coming close to the coast, makes the interpretation of isohalines in Fig. 44 uncertain; the possibility of their confirming the conclusions drawn from temperature, that subsidence is in progress, is discussed on pp. 200–201.

GUAÑAPE ISLANDS

The section illustrating salinity distribution off the Guañape Islands is typical of upwelling in evenly stratified water, and isohalines resemble isotherms. The comparative homogeneity of the upper layers may be taken to indicate that the subtropical water has been mixed with the lower layers by upwelling, and that the highly saline warm-water wedge is away from the coast (see Figs. 48 and 16).

LOBOS ISLANDS

Salinity here shows even greater homogeneity inshore, together with greater dilution of the upper layers. In this respect the lines off the Guañape Islands, Lobos Islands and Punta Aguja make a progressive series (cf. Figs. 48, 47 and 46). A layer of slightly more saline water lying at the surface within 50 miles of the shore is shown to have a comparatively high temperature, and it may be supposed to be an eddy.

PUNTA AGUJA

Homogeneity in the upper 400 m. is carried even further off Punta Aguja. The appearance of sinking water at 5 miles offshore is not shown by isotherms which may perhaps reflect a slow speed of movement.

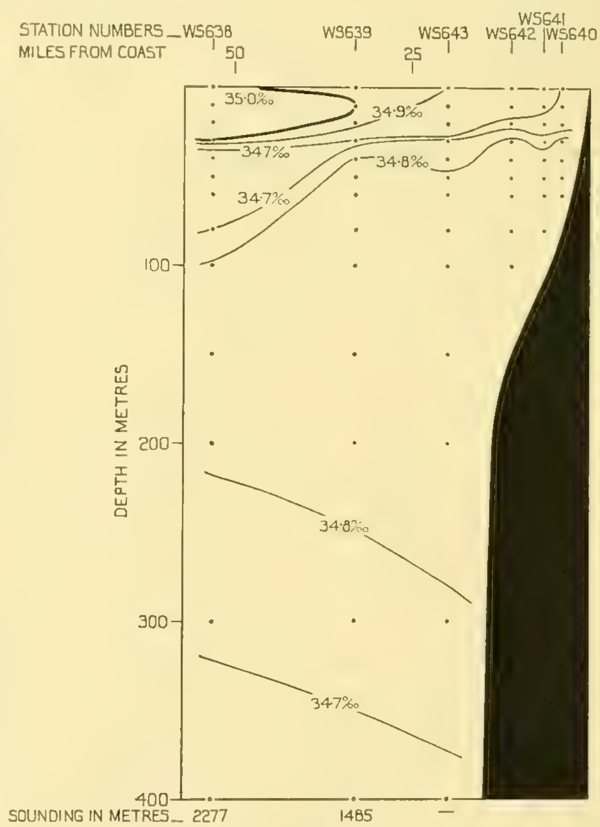

Fig. 43. Distribution of salinity. Section off Arica, June 19–20. The position of the section is shown in Figs. 2 and 11; the corresponding temperature section in Fig. 31.

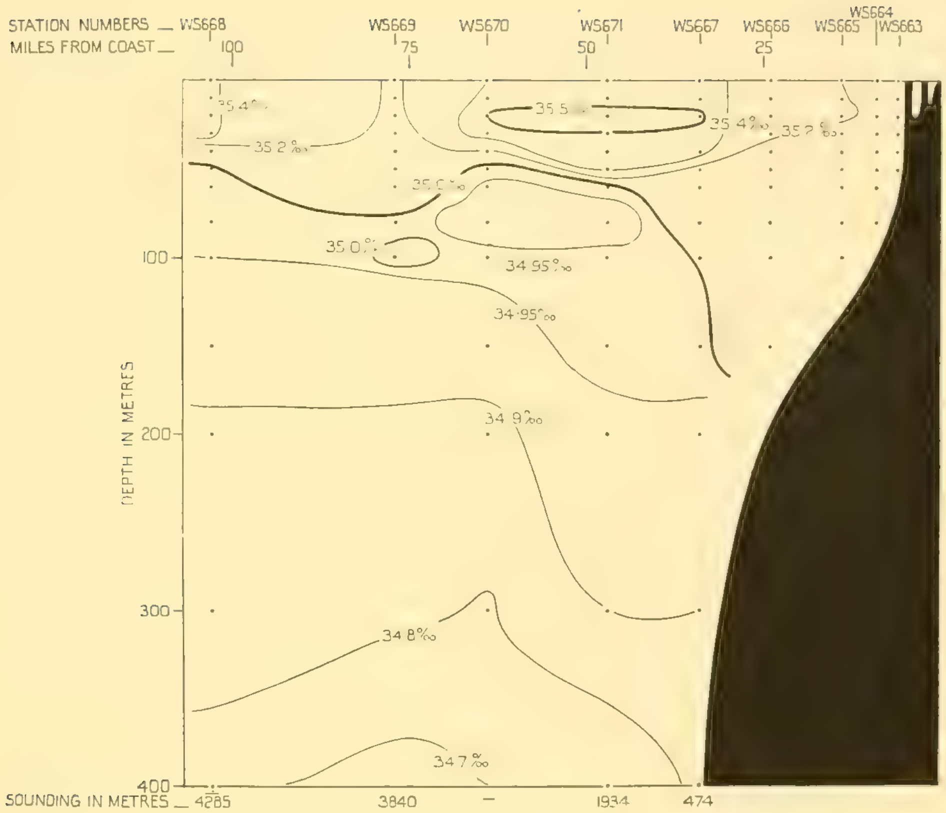

Fig. 44. Distribution of salinity. Section off Callao, July 1–3. The position of this section is shown in Figs. 2 and 10.

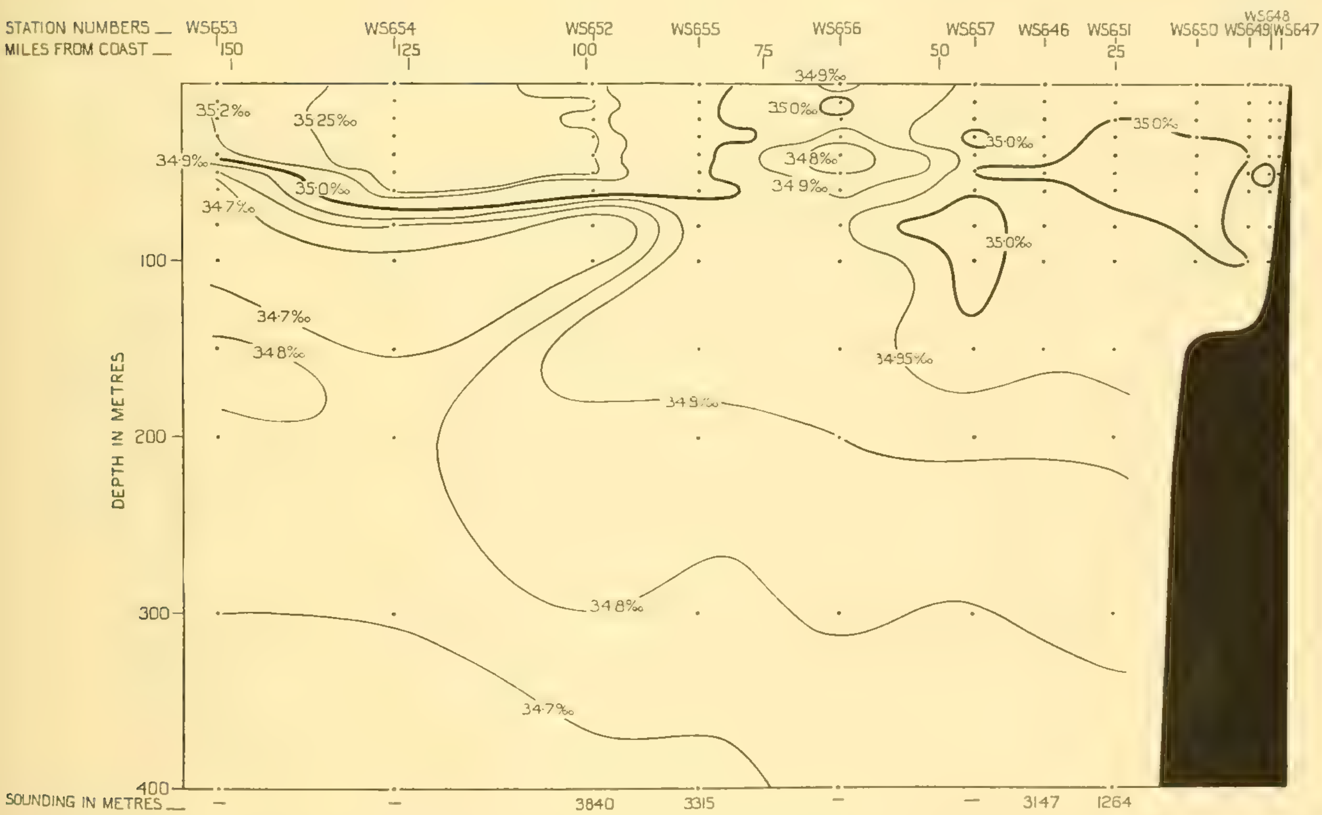

Fig. 45. Distribution of salinity. Section off San Juan, June 22–24. The position of this section is shown in Figs. 2 and 11. Temperature sections corresponding to the Figures on this page are illustrated on p. 149.

Fig. 46. Distribution of salinity. Section off Punta Aguja, July 21–23. The position of this section is shown in Figs. 2 and 12; the corresponding temperature section, in Fig. 36.

CAPO BLANCO

At Capo Blanco, surface salinity is lowered from two causes: at the surface by the southerly projecting tongue of the Equatorial Counter-current, and from below by upwelling. The upwelling which is seen in Figs. 41 and 50 to be induced offshore, and the southerly intrusion of equatorial water seen in the poorly saline hot-water tongue, are both probably indications of the divergence of the Peru Current from the South American coast. At a depth of 40–120 m. a mid-water tongue of higher salinity (35·10 ‰) represents an advance of subtropical water towards the coast, presumably to compensate for the upwelling water.

SANTA ELENA

The mid-water tongue noted off Capo Blanco is drawn both northwards and towards the Ecuador coast, beneath the Equatorial Counter-current. This may be seen in Fig. 49, which represents a section in two planes. On the right of the section, Sts. WS 715–719 run east and west off Santa Elena. On the left, Sts. WS 719–726 run north-east by north and south-west by south, that is, they run very nearly at right angles to those off Santa Elena: they run across the direction of the Peru Current on its course from South America to the Galapagos Islands. At this stage the current represents the transition between the Peru and the South Equatorial Currents. The observations off

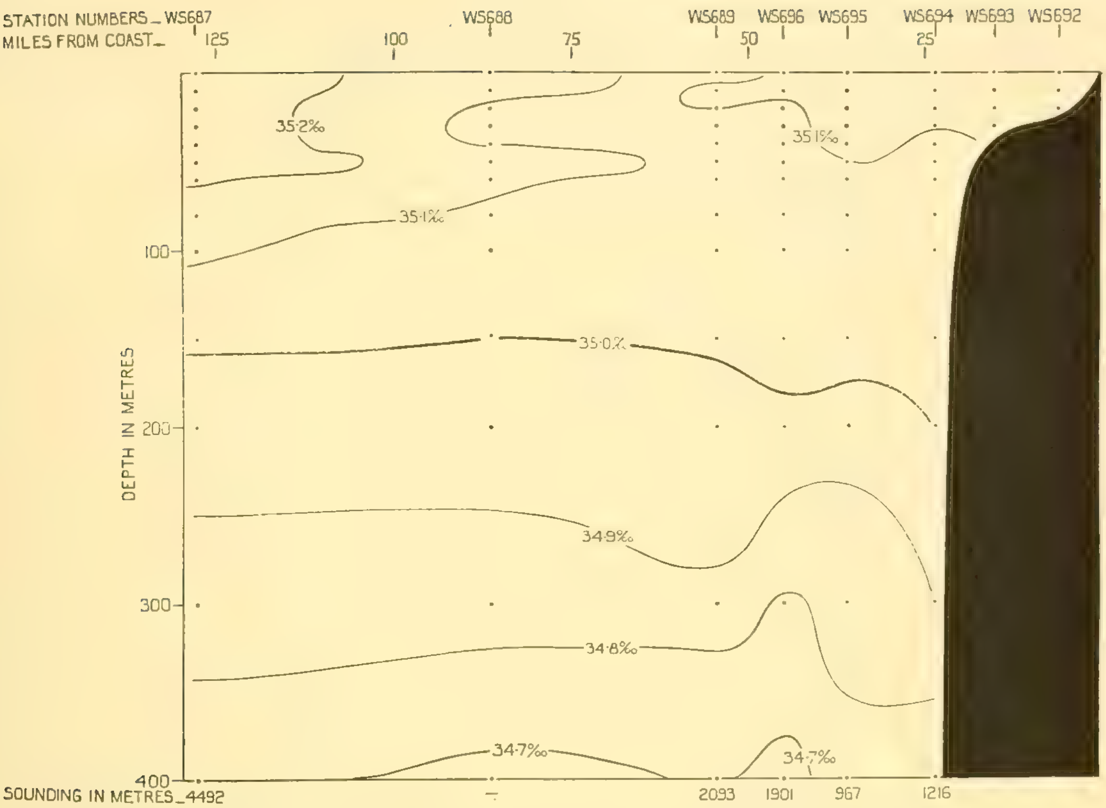

Fig. 47. Distribution of salinity. Section off the Lobos Islands, July 17–20. The position of this section is shown in Figs. 2 and 12.

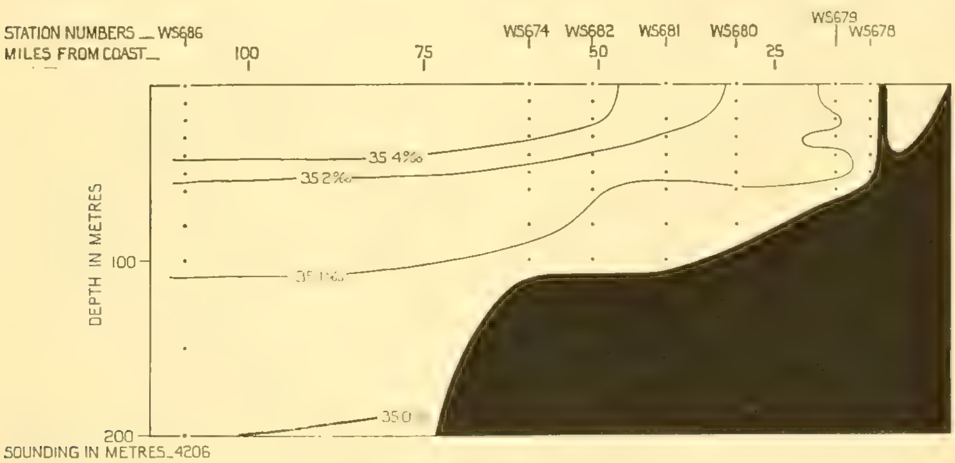

Fig. 48. Distribution of salinity. Section off the Guañape Islands, July 10–11. The position of this section is shown in Figs. 2 and 13.

Temperature sections corresponding to the Figures on this page are illustrated on p. 155.

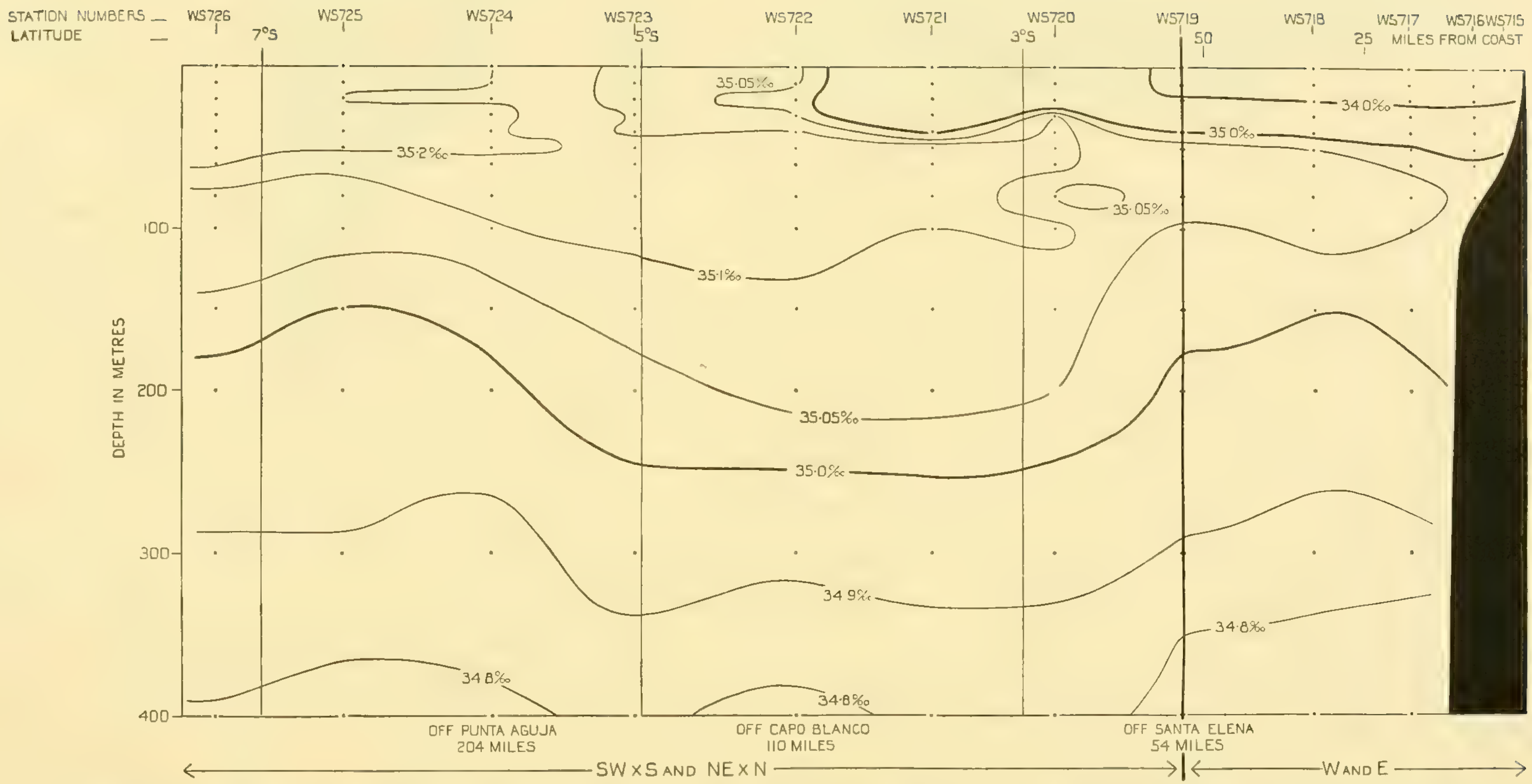

Fig. 49. Distribution of salinity. Section off Santa Elena (Sts. WS 715–719) continued in another plane (Sts. WS 719–726), July 31–August 4. The latter cuts the current as it leaves the Peruvian coast on its way to the Galapagos Islands. The position of these sections are shown in Figs. 2 and 71. The respective temperature sections are illustrated in Figs. 39 and 69.

Santa Elena show the poorly saline water of the Equatorial Counter-current extending to a depth of about 40 m. Beneath is a mid-water tongue of subtropical water which may be traced southwards from Sts. WS 719–724, when it comes to the surface.

SEASONAL CHANGES

Opportunities of repeating work occurred twice: the line off Callao was repeated after a period of seven weeks: and during this period a series of observations was carried out at one position near Palominos Island. Repeated observations are useful as controls by illustrating the kind of changes that occur over relatively short periods; they may also illustrate the changes due to season and they emphasize the limited usefulness of observations made at only one time of the year, and even more so of isolated observations.

The repeated observations off the little island rock of Palominos were made on position 12° 09′ 30″ S, 77° 15′ 00″ W in 60 m. of water; the results are plotted in Fig. 51. The depths of certain isotherms at various dates are indicated by continuous lines (the 15·5° C. isotherm by a thickened line). The oscillating nature of the temperature over the stated period is at once apparent. From June 26 until the middle of the first week in July the temperature of the whole column of water rose, and at the surface from 16·85 to 17·33° C. Then followed a sharp reaction, and during the subsequent

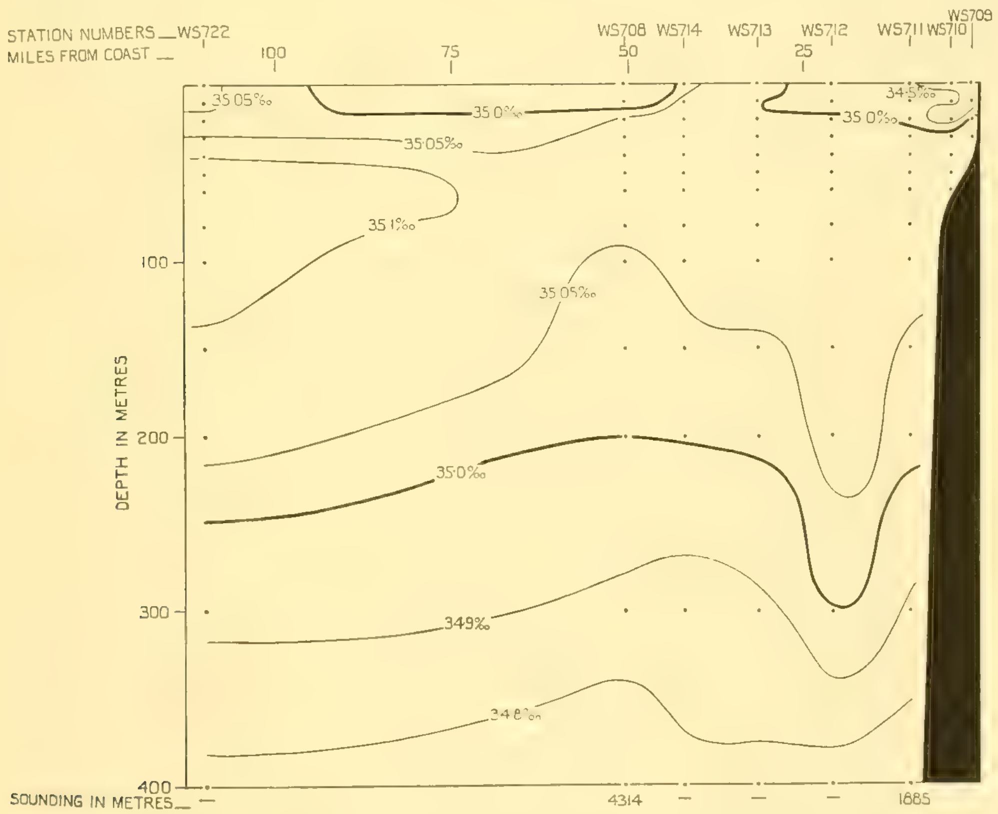

Fig. 50. Distribution of salinity. Section off Capo Blanco, July 24–26. The position of this section is shown in Figs. 2 and 70; the corresponding temperature section, in Fig. 41.

four weeks to August 7 the temperature dropped to less than 15° C. It then rose again, reaching 15·73° C. at the surface on August 20.

The diagram raises two points of interest, the connection with available wind records, and the differing composition of the water on July 8 and August 7. On July 8 the temperature gradient from 15·5° C. near the bottom to 17·33° C. at the surface amounted to 0·38° per metre. On August 7 the water was cool throughout, the gradient from 14·56° C. at the bottom to 14·88° C. at the surface being about 0·005° per metre. From this it follows that all the water off Palominos Island on August 7 was upwelled water and that it was derived from the 14–15° isothermal depth which at this time of the year off Callao lay at about 80–120 m.

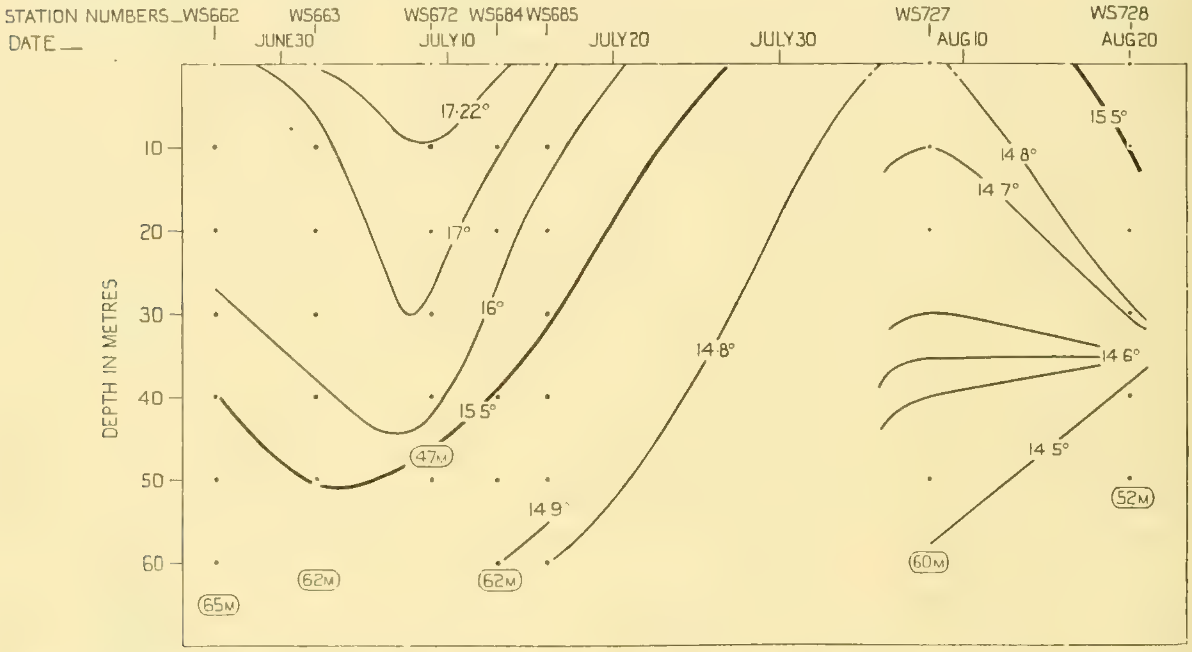

Fig. 51. Diagram illustrating temperature changes off Palominos Island in the period June 26 to August 20.
Note. The depth scale is nearly × 5 that of the sections; the sounding in metres is given at the appropriate depth for each section.

Table VII. *Relation between inshore surface temperature and the strength and direction of wind at Palominos Island*

Date	Temperature ° C.		Wind	
	Mean rise per day	Mean fall per day	Mean vector	Force miles per day
June 25 – July 8	0·04	—	S 17° E	4·3
July 8 – Aug. 7	—	0·082	S 26° E	7·0
Aug. 7 – 20	0·065	—	S	2·3

A connection between available wind records and temperature changes off Palominos Island is suggested in Table VII. The eight weeks June 26–August 21 are divided into three periods each corresponding to a period of rising or falling temperature, and the amount of temperature change is expressed as the mean rise or mean fall per day. The winds recorded by the 'William Scoresby' in this area during these periods are expressed as a mean vector for each period. Two possible correlations are to be noted: firstly that the greater rise in temperature accompanies the least wind force, and secondly that the cooling tendency follows the wind with the largest easterly component. The wind records are not as precise as could be desired; they were made quite irregularly between

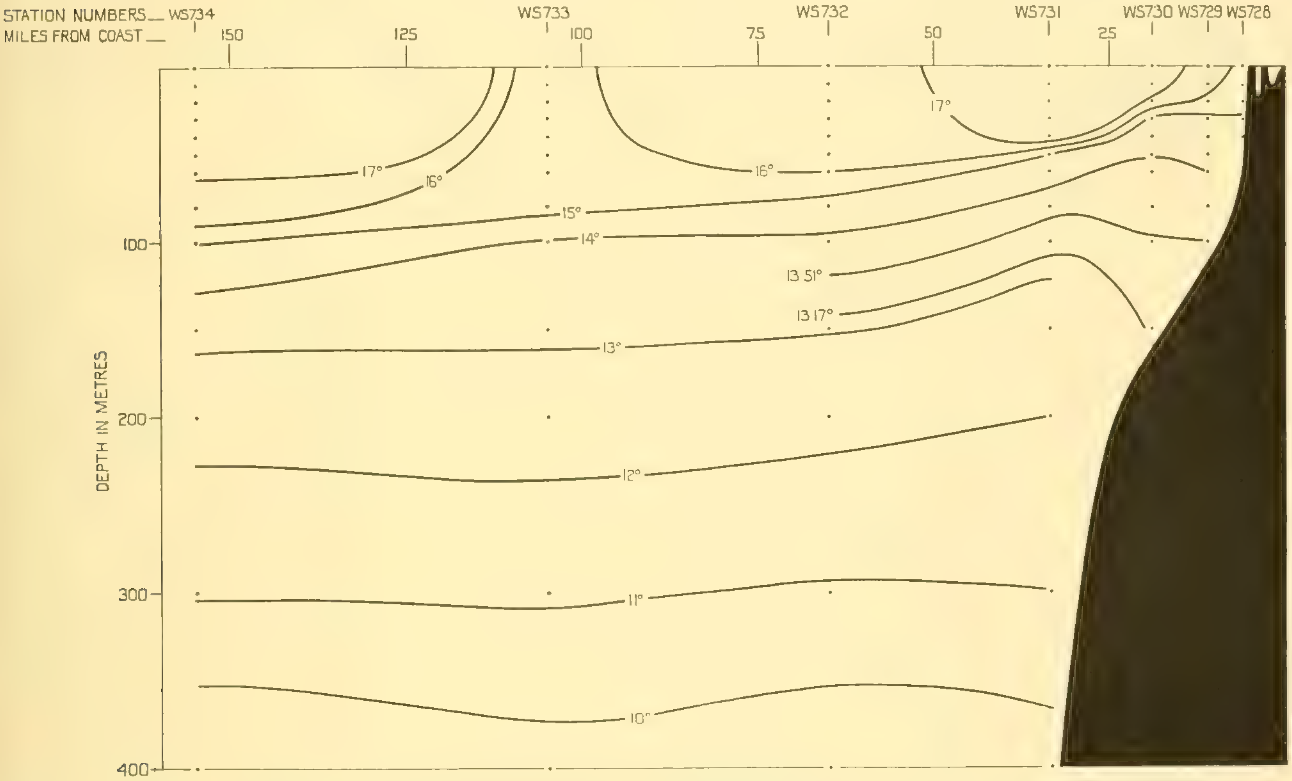

Fig. 52. Distribution of temperature (° C.). Section off Callao, August 20–21. The temperature section of July 1–3 is given in Fig. 32.

June 26 and August 21 and in the coastal region between the parallels lat. 10–14° S. There are no records in the exact neighbourhood for 19 days from July 17 to August 4, and it may be that records made in harbour bear little relation to winds out to sea. The means of all these wind records, however, fit the temperature changes, although perhaps not quite so well as might have been expected from the results obtained off Antofagasta and the Guañape Islands. An alternative interpretation is discussed on pp. 209–10.

The line of stations repeated off Callao on August 20–21 differed little in general plan from that of July 1–3, although the water was generally cooler. The water of 18° and 19° C. had disappeared or cooled down (Fig. 52), but the warm-water wedge was still to be identified as a trough of water of about 17° C., and the temperature of the open ocean at 155 miles from shore was also 17° C. That the lowered temperature out to sea

was partly the result of vertical mixing is suggested by the greater uniformity of the upper 60 m. and by the fact that in August water even at 120 m. was warmer than at corresponding depths in July. Perhaps as a consequence of this lesser stability, upwelling happens from greater depths in August than in July. The fact that the warm-water wedge has moved closer inshore and has lost its former sharp distinction is also of interest. In Table VIII the July and August lines are compared in greater detail.

Table VIII. *Seasonal differences in hydrological conditions off Callao*

Date ... ... Length of line	July 1–3 103 miles	August 20–21 155 miles
Temperature:		
Offshore: surface	18·39° C.	17·16° C.
120 m.	13·48° C.	14·31° C.
224 m.	12·00° C.	12·02° C.
Inshore: surface	17·22° C.	15·73° C.
Probable depth of water affected by upwelling	0–80 or 100 m.	0–150 or 200 m.
Warm-water wedge:		
Temperature	19° C.+	17° C.+
Miles from shore	About 33–65 miles	About 14–51 miles

Observations of a seasonal character were also obtained at the conclusion of the survey on returning southwards in August and September. The surface temperature off both Chile and Peru was cooler in August and September than earlier in the year. This cooling is attributable to the effect of winter, but while it holds without exception for the majority of the coast, the effect was not found between latitudes 34 and 39° S. Here the surface temperature in September showed a rise over that of May. The comparisons are made between observations in the same locality on the northward and the southward journeys and only between those which were separated in time by more than three weeks: twenty-two such series of observations are available, the broad results of which are given in Table IX. The rise in temperature between 34 and 39° S may be correlated with the Chilean monsoon, which will be shown on pp. 226–7 to be attended by a change in the direction of the surface current. This observation, then, enables us to fix the southern boundary of the Peru Coastal Current.

Table IX. *Changes in surface temperature from autumn to winter between* 8 *and* 47° S

Lat. ° S	Months compared	No. of comparisons made	Mean weekly change ° C.
8–33	May–July August	13	−0·23
34–39	May September	5	+0·01
40–47	May September	4	−0·19

COLOUR OF THE CURRENT

Buchanan (1910) has observed that surface water of the open ocean is to be referred to one of three colour types, ultramarine, indigo and olive green, characteristic respectively of tropical, temperate and polar regions. The colour of coastal waters is, of course, modified by a variety of causes, and the commonly occurring green in the Peru Current, like the olive green of the Antarctic, is attributable to an abundance of diatoms. Since colour is an accepted characteristic of the Coastal Current, it is well to consider how far our own observations uphold the records already made.

In the neighbourhood of Chiloe, which should be classed as temperate, the water was definitely green (Plate XVI, fig. 1) at least as far as 60–70 miles from land, and continued so well to the north of Cape Carranza. Farther up the coast in 25° S, the sea was bluer: but it had a more greenish look at 6 miles from land where the temperature was low (14·20–14·45° C.)[1] than at 10 miles where the temperature was higher (16·79° C.) (Plate XVI, figs. 2 and 3). But at Antofagasta conspicuous greenness of the water was noteworthy (Plate XVI, fig. 4): this persisted as far as 7 miles from shore and then seemed to shade off slightly, but the onset of night prevented our recording the change into ultramarine, the colour observed on the following day at 46 miles from land (Plate XVI, fig. 5). A gradual change from green inshore to blue in the open ocean continued the normal state until the arrival of the ship at Pisco, where water of an almost unbelievable bright salmon colour was found at midday: the vividness somewhat abated after noon (Plate XVI, fig. 6). The plankton in this region included quantities of a flagellate pigmented with red, and many of the other organisms such as the Foraminifera and the smaller Crustacea had oil globules strongly coloured orange. We believe that the explanation of colour in the sea water lies in these organisms, and it seems probable that the altering of tone in the afternoon may be due in some measure to vertical migration. The hydrology of the water is referred to on p. 216 and a possible connection with the virazon is noted on pp. 210, 232 and 233. Large Medusae, which were noted at other localities also, attracted attention at Pisco by blocking the ship's condenser intake; their numbers made it impossible to keep the intake clear, and the engine-room machinery was closed down until the moment of departure. Medusae were similarly abundant at Sts. WS 712 and 713, where they choked the nets and prevented collection of plankton samples. Their swarming on the borders of water having a high and low temperature is noteworthy.

At some 50 miles off San Juan streaks of a reddish discoloration were met with, they were just under the surface of a grey sea and in the fading light of dusk had a brick red and scum-like appearance.[1] Individual organisms could not be distinguished in the sea, but our nets took up an almost incredible quantity of Euphausian cyrtopias in the course of 5–10 min., affording a parallel to the swarms of *Euphausia superba* which sometimes colour the Antarctic with patches varying from ochre to brick red.

On passage from Pisco to Callao the ship encountered changes of colour for which it is less easy to account. At a point 15 miles off the coast she entered a zone of brownish

[1] This record is not illustrated.

water which extended in a north by west to north-north-west direction for 15 miles, as far as San Lorenzo Island off Callao, where its outer boundary was approximately 7 miles off the coast, and curved sharply shorewards. The southern edge was ill-defined, being marked by occasional patches a few yards wide of rusty brown foam; soon the water acquired a full tawny olive and russet colour, and the foam in the wake of the ship had a rusty appearance. The northern edge, on the other hand, was sharply defined and lay conspicuous between the brown of the patch and the clear bluish green water outside (Plate XVI, figs. 7 and 8), their respective temperatures, differing by half a degree, were 16·85 and 16·34° C. Nets were towed on each side of the boundary at Sts. WS 661 and 662, which were 2 miles apart. In the brown patch at St. WS 662 the scum-like discoloration seemed restricted to the surface, where bubbles and birds' feathers floated; but no connection was discovered either between the surface scum and the multitudes of the Peruvian cormorant known locally by the name of guanay[1] which frequent these parts, or with the shoals of fish upon which the latter feed. The plankton seemed equally abundant in the clear and the discoloured water. If the excreta of sea birds were discharged into the sea on a large scale they might produce the oily scum, which in effect bore a resemblance to a surface film of fuel oil. The Peruvian naval base lies near by, but it seemed unlikely that petroleum was the cause owing to the scarcity of dead birds. Although the phytoplankton catches were not large and the scum suggested no resemblance to the "yellow lenses" described by Sheppard (1931) off the coast of Ecuador, yet the possibility that such a mechanism may have been at work here cannot be disregarded (pp. 232–3).

Off Salaverry, coastal waters of a conspicuous olivine colour (Plate XVI, figs. 9 and 10) extended 10 miles seaward: farther from land the hue changed to a sea green, and a similar sequence from chalky green to blue, always graduated, was observed off Punta Aguja and again off Talara. Near the Guañape Islands irregular patches of khaki were observed, but the sun set shortly afterwards and their extent was not recorded (Plate XVI, fig. 11).

A patch of brilliant yellow due to a swarm of a colonial Radiolarian, probably *Collosphaera*, was met at some 180–200 miles off Punta Aguja. It was unlike any patch met close inshore, having more the appearance at a distance of the straw-like discoloration of the sea described by Collingwood (1868) for *Trichodesmium* and frequently witnessed in the Atlantic during the Discovery investigations.

On July 16 at 63 miles from land in 10° 32′ S, over deep water, the sea was the indigo of temperate regions (Plate XVI, figs. 12 and 14) instead of the ultramarine so commonly found in the open ocean in these parts, an effect almost certainly due to cloud (Rayleigh, 1910). On the return voyage from Callao to Valparaiso, two sketches were made in the open ocean at 255 and 32 miles from land (Plate XVI, figs. 13 and 15). The former is almost identically the same hue as that figured in Plate XVI, fig. 5, and is useful as a control; the other has a deeper tint, no doubt owing to the rougher sea prevailing at the time.

[1] *Phalacrocorax bougainvillii*, a white-breasted cormorant.

The accuracy of Buchanan's observations is confirmed by our own, made independently, and his notes which describe the water as "green", "chalky green", "olive green" and "ultramarine" express very clearly the colours in Plate XVI. His reference to water of a greenish blue off Antofagasta finds a counterpart in our description of it, and the chalky green water found by him off Payta is evidently the same as the colour we met off Salaverry, Punta Aguja and Talara. His terminology is sufficiently accurate to warrant the conclusion that he did not come across the patches of orange, russet brown, and khaki noted in the other sketches. The small distances from the shore at which chalky green water was found by him agree with our own observations; 5–10 miles is his usual limit, but in his note of greenish water at 15 miles offshore between Chala and Arica he seems to be describing a hue of ultramarine.

On no occasion during the present survey were cold patches of blue oceanic water met close inshore as described by Buchanan at Huasco and Carizal. A hypothetical significance has been attached to these cold "blue patches" because they were supposed by him and by certain later writers to indicate the presence of recently upwelled water which, having come from a depth below the layer of active photosynthesis had a minimal phytoplankton content. According to our own observations, the colour of water which appeared to be upwelling close under the coast differed in no remarkable way from the surrounding water; the areas of green, orange, brown, khaki and chalky green all merging gradually, were suffused with the surrounding waters. The one exception to this rule, the line of demarcation between water coloured russet brown and that of porcelain blue off San Lorenzo Island, has already been noted. When we saw the blue we were convinced that we had come upon a "blue patch": closer examination, however, proved that this could not be so, for the blue water was continuous with oceanic water to the west, thus its area exceeded that of the brown water and it was not a patch within the latter. Moreover, the water did not appear to be actively upwelling (see pp. 170 and 209–10).

LIFE IN THE CURRENT

In contrast to the attention that has been paid to the physical aspects of the Peru Current its fauna and flora have been neglected. Darwin (1845), who spent upwards of six months on the coast, makes no reference whatever to the colour of the current or to its marine life. This is surprising in view of its abundance, for it is rich alike in species and in numbers of individuals. More recently the larger animals and especially those of economic importance have aroused interest, but little is known of the plankton, the ultimate source of food of the larger animals and the cause of the colour of the current. During the present survey collections of phytoplankton and zooplankton were made over the whole area, but a detailed account will not be possible until analyses are available and the quantities of the various species have been estimated. In this and the next section, some results are given which suggest possible correlations with the physical and chemical conditions. These notes are of a provisional character and are only given

in their present stage because a description of the Coastal Current which took no account of its marine life would leave much of significance unrelated to the oceanography of the region as a whole.

Place names on the west coast such as Ballenas Island, Lobos de Tierra, Guañape Island, and Pescadores Island evince the prominence of whales, seals, birds and fish in the coastal waters: but Invertebrata were also to be seen, and at night squids were frequently attracted to the surface by the ship's lights. The great majority of the larger animals, like the patches of coloured water, were restricted in their distribution and were met only within the coastal zone, but squids were as far out as 150 miles from the coast (Plate XV).

Among the smaller Cetacea, three or four kinds of dolphin were seen. In the Magellan Straits, *Cephalorhynchus commersoni* attracted attention partly because of its conspicuous white body outlined by black pigment on nose, fin, flippers and tail flukes, and partly because of the quickness with which it takes breath. Farther up the coast we saw porpoises swimming at a saunter in the calm waters of Coquimbo Harbour, and schools of dolphin in the open sea. At the time of our visit a whaling company was at work off Corral and off the island of Huafo in southern Chile, where Humpback, Sei, Fin, Blue and Sperm whales may be taken; but to-day they are met with in decreasing numbers and the whaling stations are closing. Of the toothed whales we met six Sperm between the latitudes of 12 and 26° S, and one or more schools of blackfish (*Globicephalus*) off Peru. Of the Whalebone whales, Rorquals were little less restricted than Sperm whales: five were met in the land-locked Patagonian Channels and a round dozen off the Lobos Islands; in this region, having the appearance of an eddy, plankton was rich (see p. 220). Anchovy (*Engraulis ringens*) also were presumed to be plentiful since, in the presence of these whales and of bonito breaking surface, flocks of birds at rest upon the water looked as though they had been feeding.

Seals and birds, as they have terrestrial haunts, were not included in our regular observations, but a visitor travelling northwards cannot fail to be impressed by their steadily increasing numbers at every port of call from Southern Chile to the Lobos Islands; by the sight of pelicans in flight and by his first introduction to guanays in close-packed flocks that look like black rafts upon the water. We first met them, in their tens of thousands, at Antofagasta; and behind them pelicans moved slowly, seeming secure, until the scuttling of guanays indicated the approach of danger (Plate XV, fig. 2). For the habits of these, the piquero (*Sula variegata*), the camanay (*S. nebouxi*) and the many other species nesting on these coasts, the reader is referred to *The Bird Islands of Peru* (Murphy, 1925): see also Plate XV, figs. 1 to 3.

The distribution of sharks is worth noting because they are examples among vertebrates of the influence of temperature upon the distribution of marine organisms. A genus believed to have been the hammer-headed shark was in large numbers off Capo Blanco in the hot tongue of the Equatorial Counter-current (p. 158) but nowhere else off Peru. Other genera (not identified) were frequent off Chile between latitudes 18 and 36° S, but were not seen farther to the north. The hammer-headed shark, like

the frigate bird which is also of tropical habits, is seldom found farther south than Talara in the cool water of the Peru Current.

Squids were widely scattered and they varied in size from forms measuring a few centimetres to others reaching a metre or more in length. A squid which is referred to *Omastrephes gigas* by Wilhelm (1930), but which, as far as can be judged[1] from photographs, appears to be *Dosidicus gigas* (Orbigny), was met in great numbers washed up in the harbour of Talcahuano. We are informed by Dr Ottmar Wilhelm that this phenomenon may be a serious problem to the harbour authorities, not only because the floating bodies are so numerous that they choke the harbour and interfere with shipping, but also because of the disagreeable consequences of their decomposition. The cause of these cataclysms, which in their effects resemble those of *El Niño* off the Peruvian coast, is as yet unknown. They are described in more detail on p. 233.

ZOOPLANKTON

Light upon the distribution of the larger animals seems to have been thrown by the catches of zooplankton. The mass of plankton has been consistently large, but the average volume per net was slightly larger in the lower latitudes off Peru than in the Chilean latitudes, as is shown in Table X. The contrast is greater if Euphausians are considered by themselves. Off Chile, catches of Euphausians were more frequent; they were consistently larger and their bulk occupied a very much larger proportion of the total plankton catch. Off north and central Peru, on the other hand, the plankton had a small Euphausian element, but the total bulk was otherwise greater. The krill and the whales seem to be correlated off Chile; the guano industry, anchovy and heavier plankton, off Peru. Krill is of course the staple of whale food in the Antarctic: off Corral, whales have been taken with *Euphausia vallentini* in their stomachs, but whether in these latitudes they feed in the proper sense as they do in the Antarctic is doubtful. With rich plankton off Peru, we find the enormously heavy shoals of anchovy, and upon them the birds, seals, dolphins, bonito and other animals are said to subsist.

Table X. *Relative abundance of Euphausiacea and of other animal plankton off Chile and Peru as shown by the volume of settled organisms*

Latitude ° S	Total No. of plankton samples examined	Total plankton mean vol. per sample c.c.	Euphausiacea mean vol. per sample c.c.	Other zooplankton mean vol. per sample c.c.	No. of samples containing Euphausiacea
2–14	132	360	25·5	334·5	12*
14–36	155	225	116	109	42*

* These figures include only samples in which the volume of Euphausiacea exceeds 200 c.c.

[1] I am indebted to Mr G. C. Robson for this suggestion.

PHYTOPLANKTON

Phytoplankton on the west coast is of interest, not only as the link between the productivity of the various upwelling centres and the zooplankton, but also in relation to the green colour of the current. In giving a preliminary account of the catches, we had no better measurement than the volume of settled organisms. The method based on chlorophyll estimation, recently introduced into this country by Harvey (1934), was not available to us in 1931. It is well known that as a result of their different shapes, the secretion of slime, etc., different species of diatoms pack differently, and that consequently this method can be used only to distinguish major differences in the size of catches. As, however, catches in the Peru Coastal Current varied in volume from less than 1 to 390 c.c., the method may be employed with some possibility of success. The amount of plankton at each station is given in Appendix I as the volume of settled organisms (to the nearest 25 c.c.), taken by the 50-cm. net from 100 m. to the surface.

When these data are plotted on a chart, the heavier catches are found to occur in groups; they thus formed areas of concentration and did not seem to be scattered at random among the poorer catches. Some twelve such patches of higher concentration can be made out; they were arranged irregularly from south to north and are indicated in heavy type in Appendix I. While they were more frequently met inshore than offshore, four of the patches occurred at more than 30 miles from land off Cape Carranza, Caldera, San Juan and Callao. This is interesting, since it has frequently been held that rich phytoplankton is restricted to the green water in the upwelling zone[1] (see p. 222).

If the mean volume of phytoplankton at varying distances from the shore is computed from all samples collected during the survey, it is seen to be greatest at 4–5 miles offshore and less at lesser distances (Table XI). At greater distances the quantity of phytoplankton first fell off and then reached a second peak at 56–100 miles offshore. As it

Table XI. *Mean concentration of phytoplankton at different distances from the coast*

Distance from shore miles	No. of observations	Mean volume of phytoplankton
<2	9	30·6
2–3	9	55·5
4–5	13	64·6
6–10	13	42·5
11–25	19	37·0
26–55	24	48·0
56–100	17	75·0
101–150	6	41·6
151–200	2	37·5

[1] Michael (1921) claims to have identified the seat of greatest phytoplankton production with that of upwelling on the coast of California. We are not prepared, however, to accept the published data as evidence on this point, for the seat of upwelling seems to have been situated not in the region where phytoplankton was examined, but in the neighbourhood of islands at some distance off.

seems likely that, on the average, phytoplankton would reach its maximum development in one zone, at some fairly well-defined distance from land, the bimodality of this curve suggests that the area on this survey has been inadequately sampled.

The broad characteristics of the patches noted above, including their position, size, and concentration, are given in Table XII; the data are insufficient to show whether they are comparable to the phytoplankton concentrations described by Savage and Hardy (1935): and if, as appears likely, the area has been inadequately sampled, it is unsafe to draw far-reaching conclusions. It is interesting to note, however, that the size of patches increases with the distance offshore. This result would not have been produced simply by the wider spacing of offshore stations if the heavier catches had been interspersed with poorer catches, and consequently it may illustrate that patches have their origin near the coast, in the upwelling zone, increasing in size as they drift out to sea.

Table XII. *Size and distribution of patches of phytoplankton met with on the west coast. At those localities where patches were not recognized, the fact is indicated by a negative sign*

Distance from coast miles	Span of patch miles	Mean vol. of settled phytoplankton c.c.	Dominant genera	Locality	Latitude S
—	—	—	*Chaetoceros*	Santa Elena	02° 11′
<2	2	50	*Chaetoceros*	Capo Blanco	04° 19′
0–10	10	179	*Chaetoceros* *Coscinodiscus*	Punta Aguja	05° 44′
5–15	10–15	25–50	*Coscinodiscus* *Chaetoceros*	Lobos Islands	07° 05′
—	—	—	*Coscinodiscus*	Guañape Islands	08° 47′
5–10	10–20	87·5	*Chaetoceros*	Callao (August)	12° 29′
65–150	100	66·6	*Planktoniella* *Rhizosolenia*		
—	—	—	—	Callao (July)	12° 29′
0–15	15	25	*Chaetoceros* *Thalassiosira*	San Juan	15° 50′
45–85	40–50	175	*Chaetoceros* *Rhizosolenia*		
—	—	—	—	Arica	19° 26′
—	—	—	—	Antofagasta (north)	23° 12′
7–15	8–10	108	*Chaetoceros* *Corethron*	Antofagasta (south)	23° 54′
2–5	3	37·5	*Corethron* *Chaetoceros*	Caldera	27° 06′
30–50	20	25	*Planktoniella*		
—	—	—	*Synedra* *Trichodesmium* *Chaetoceros* *Corethron*	Pichidanque Bay	32°
5–15	10	55	*Thalassiothrix* *Chaetoceros* *Corethron*	Cape Carranza	35° 40′
35–85	50	135	*Chaetoceros* *Corethron* *Synedra*		

A study of the predominant genera composing the catches was made at the time of their collection by Mr G. W. Rayner to whom I am indebted for Fig. 53 and the data in Table XII and Appendix I. They show that although a cosmopolitan genus like *Chaetoceros* was represented almost universally, many of the other genera were abundant only in certain regions. Thus we may distinguish between oceanic species like *Rhizosolenia* and *Planktoniella*, and neritic species: and we may distinguish between species relatively more abundant in the north such as of *Coscinodiscus* and of *Thalassiosira* and those in the south, *Synedra* and *Corethron*. To what extent these distributions change from season to season we have no knowledge.

PHOSPHATE CONTENT

Analyses of the phosphate content of the sea water were made on nine of the lines. In illustrating the upwelling of inshore waters the results fall into line with temperature and salinity records. The general characteristics of phosphate distribution in the oceans are a high concentration in deep water and a low concentration at the surface, where in well-lit layers inorganic salts may be consumed during photosynthetic activity of the plankton. With this distribution our results agree except in those areas close to the shore where upwelling of water rich in salts has taken place, and here phosphates are in high concentration at the very surface.

The phosphate analyses were carried out by Mr A. H. Laurie who has plotted the results in Figs. 40 and 54–61 as the number of milligrams of P_2O_5 per cubic metre of sea water.[1] Each figure illustrates the phosphate values in a vertical section running transversely across the current. The sections may be arranged serially to illustrate a gradual change from the condition at Pichidanque Bay, where surface phosphates are everywhere at a minimum, to that at San Juan where rich phosphates occur at the surface for as far as 50 miles offshore. All these sections betray some trace of upwelling close inshore by the direction of the boundary between the surface waters, where depletion of phosphate has occurred, and the rich stores of phosphate in the deeper water; this boundary line is usually a layer with medium phosphate content which runs horizontally at about 50–200 m. but rises towards the surface near the shore.

Unevenness in phosphate distribution probably depends upon three cardinal factors: upwelling or subsidence of rich concentrations to and from the surface according to wind, seiche or other conditions; depletion brought about by propagation of phytoplankton; and vertical mixing of the richer and poorer waters through the action of gales and currents. To these must be added the decomposition of organic remains and salts of terrestrial origin. The common plan underlying phosphate distribution in the first seven of the nine sections just described points to upwelling phenomena as the most influential of these factors, and consequently a correlation is to be expected between the phosphate distributions and the temperature curves.

[1] In this work it was found impracticable to filter the samples before analysis. The data were not salt corrected and presumably include arsenates if present: they are therefore probably on the high side.

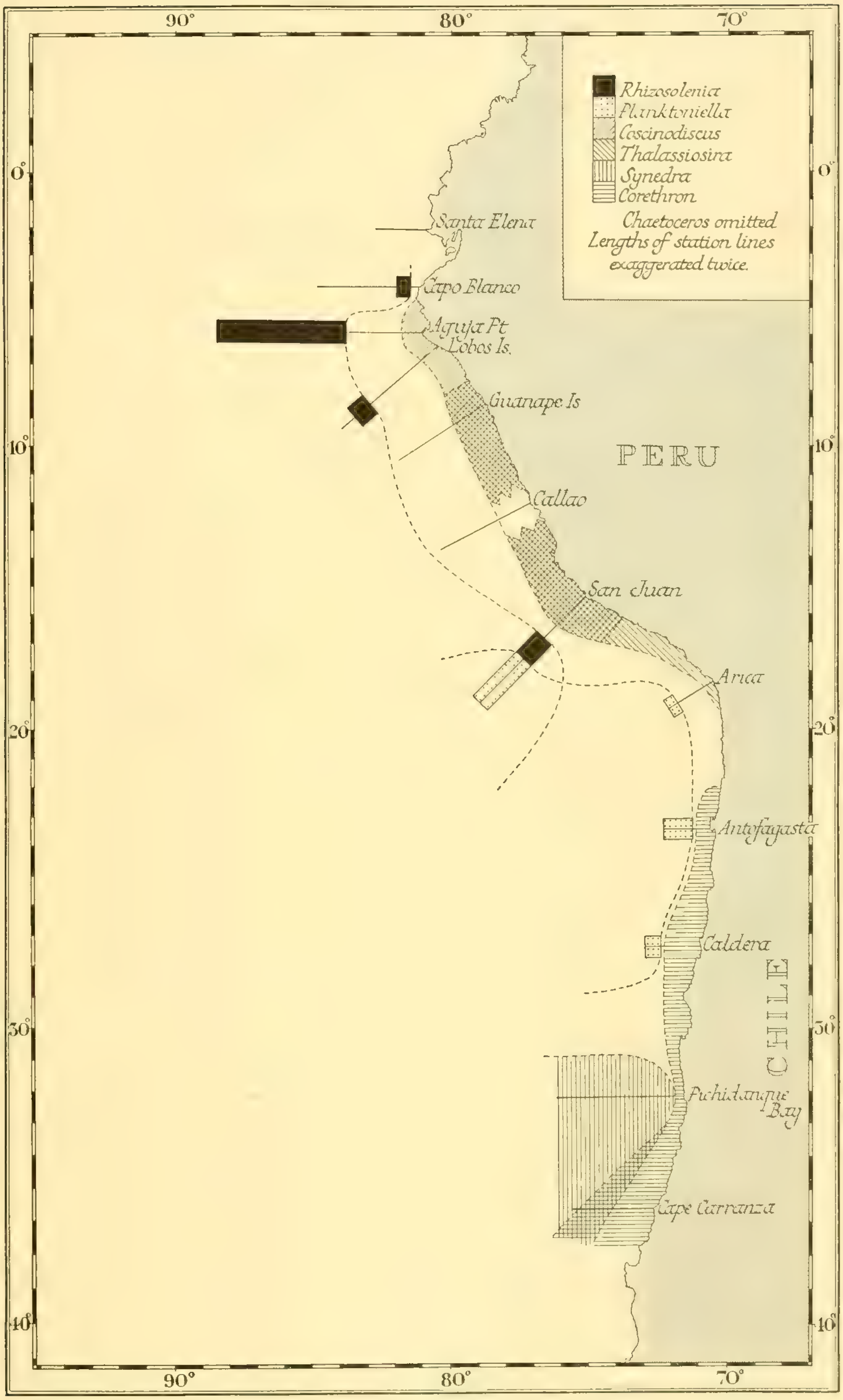

Fig. 53. Distribution of the genera of phytoplankton as found dominant at each of the localities visited between May 18 and August 1, 1931.

PHOSPHATE AND TEMPERATURE

Comparing the temperature sections of two lines which show extremes of high and low phosphate abundance, Cape Carranza and Pichidanque Bay, it will be seen (Figs. 54 and 55) that upwelling was active or had until very recently been active in the first within 58 miles of the coast, the temperature rising 2·12° with a gradient of 0·037° per mile, while in the second there was next to no upwelling except for the first few miles, the temperature showing no appreciable increase within 74 miles of the shore. The line off Caldera affords an equally good illustration (Fig. 56). The line may be resolved

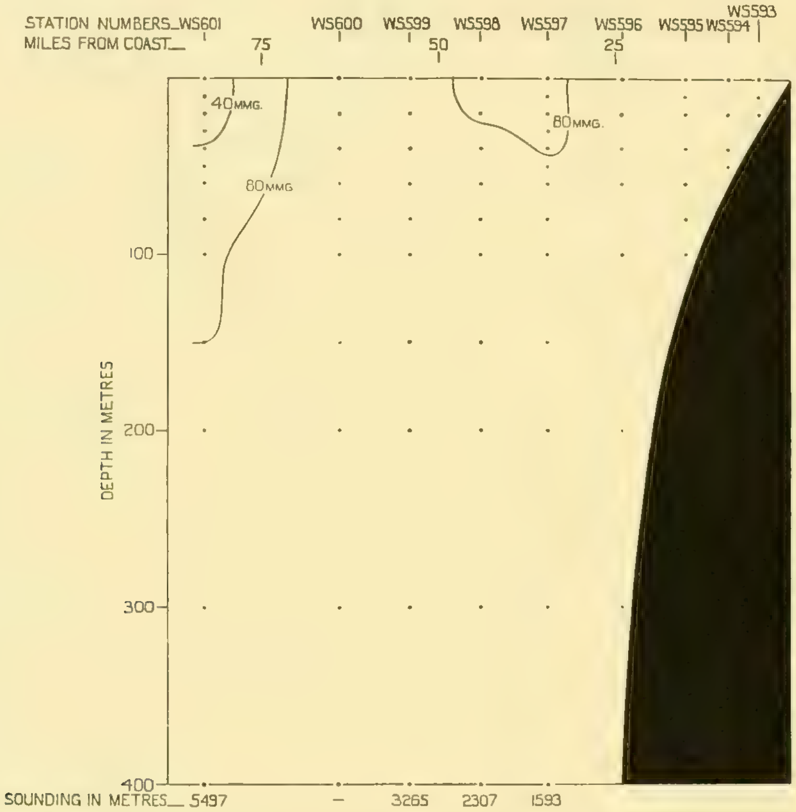

Fig. 54. Distribution of phosphate (per m.³). Section off Cape Carranza, May 18–20. Corresponding sections of temperature and salinity are illustrated on p. 138.

into two parts: within 25 miles of the shore turbulence and upwelling seem phenomenal; from 25 to 50 miles offshore the isotherms run level. Corresponding to these two parts we find that surface phosphate values in the upper layers from 25 to 50 miles are minimal, whereas in the upwelling region they are medium. Moreover, rich phosphates are nearer the surface in the upwelling region than offshore. Off Antofagasta the phosphate content at the surface changed from rich to medium with change of wind and increase of temperature (Figs. 58 and 59). Off San Juan, the surface temperatures over the regions of high, medium and low phosphate concentration are respectively 13·79–15·36° C., 16·24–17·4° C., and 18·80–19·48° C. Correlation between phosphate distribution and temperature in these five localities is straightforward because the area of disturb-

ance was amply covered by our stations. Off northern Peru, however, the breadth of cool water is greater and observations do not always extend through to typically oceanic conditions. Thus rich phosphates at the surface near the Lobos Islands may be correlated in their wide extent with the spreading seawards of the surface isotherms; but the contrast between waters that have long been at the surface and those recently upwelled is not illustrated (Fig. 60).

PHOSPHATE AND PHYTOPLANKTON

The relation between nutrient salts and phytoplankton may be shown in two ways, firstly by the occurrence of rich phytoplankton only in those areas rich in nutrient salts,

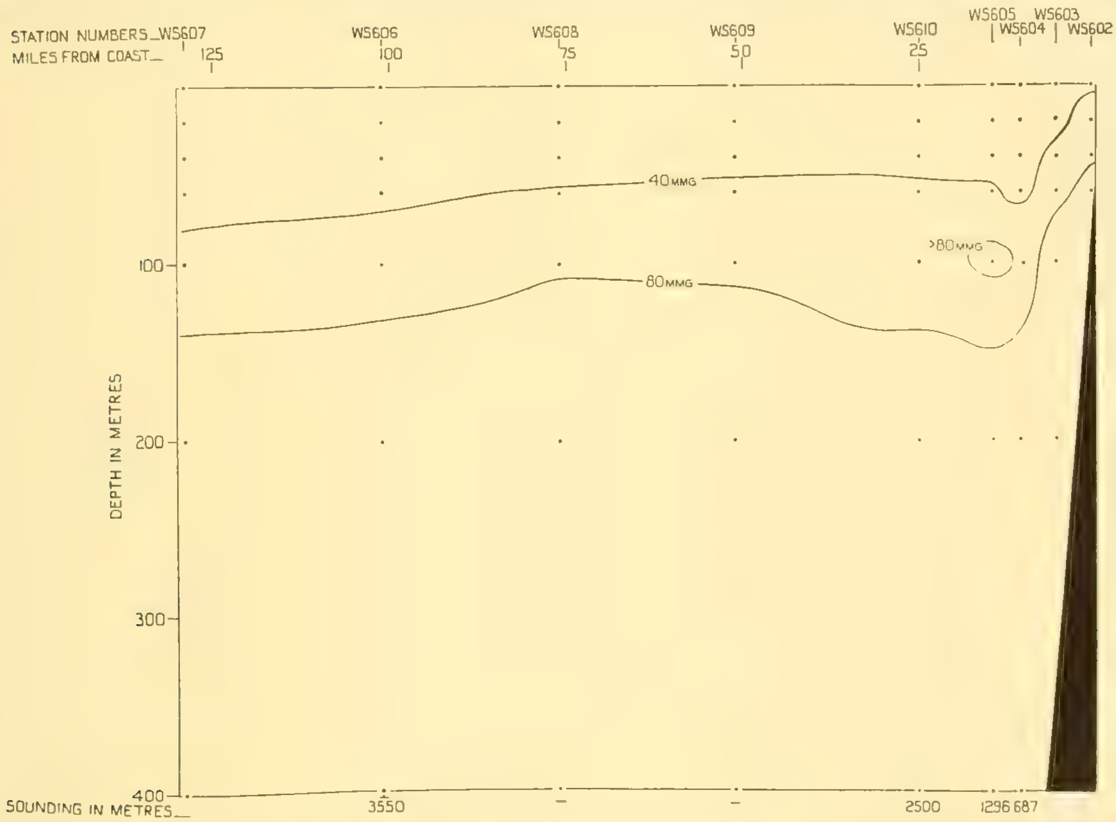

Fig. 55. Distribution of phosphate (per m.³). Section off Pichidanque Bay, May 28–30. Corresponding sections of temperature and salinity are illustrated on p. 139.

and secondly, within those areas, by the greater depletion of nutrient salts at stations where phytoplankton is thick than at those where it is poor. Table XI shows that phytoplankton is in higher concentration within 100 miles of the coast than farther out to sea. The phytoplankton inhabits the uppermost layers, and the uppermost layers are rich in nutrient salts only close to the coast. Thus regarding this part of the eastern South Pacific as a whole we note that phytoplankton and phosphate coincide in abundance along the coastal region. This coincidence in the distribution of phosphate and phytoplankton is seen to almost greater effect when the separate localities represented by our lines of stations are compared with one another. The seven lines upon which a complete series of phosphate analyses was secured have been arranged in order of

increasing plankton yield in Table XIII. The correlation between poor plankton (plant and animal) and poor phosphate, and rich plankton and rich phosphate presumably illustrates the restrictive law of population.[1]

Table XIII. *Correlation between volume of plankton and concentration of phosphate*

Locality	Plankton mean volume per station		Phosphate	
	Phytoplankton c.c.	Zooplankton c.c.	Concentration	Breadth of zone miles
Guañape Islands	<25	405	Rich	15
Lobos Islands	<25	395	Rich	40–80
Cape Carranza	76	313	Rich	70
San Juan	51	208	Rich	50
Antofagasta	25	276	Rich	25
Caldera	18	172	Medium	20
Pichidanque Bay	Very few	113	Poor	—

Rich = >80 mg., Medium = 40–80 mg., Poor = <40 mg. P_2O_5 per cubic metre.

In reviewing the phosphate concentrations on these lines, no reference has yet been made to the minor irregularities such as occur off Cape Carranza, Antofagasta and San Juan, where patches of phosphate reduced to a medium value may be met at or near the surface layers in the midst of higher concentrations; nor to the fact that rich as may be the phosphates at the surface in the upwelling region they are usually less rich than those in lower layers. The possibility of relating this reduction to the activity of phytoplankton may now be considered.

Off Cape Carranza two patches of dense phytoplankton were met: one was situated at 5–15 miles from the coast, the other offshore from 35 to 85 miles, and neither at first sight shows a direct relation to the amount of phosphate in the surface layer and to the patch of medium phosphate illustrated in Fig. 54. We may endeavour, however, to measure the reduction of surface phosphates by comparing these values with those in deeper water, say at 100 m. In this comparison the mean of the values at 0 and 20 m. may be expressed as a percentage of the mean of the values

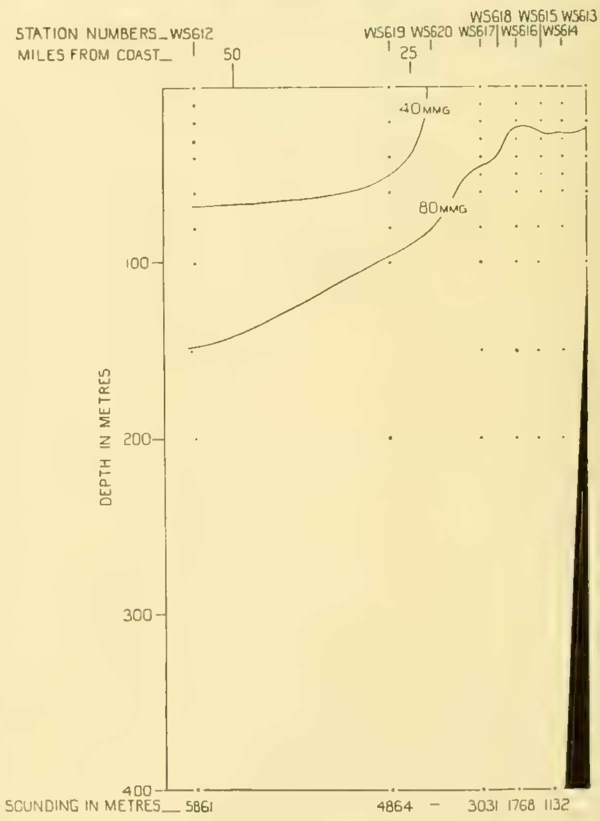

Fig. 56. Distribution of phosphate (per m.[3]). Section off Caldera, June 4–6. Corresponding sections of temperature and salinity are illustrated on p. 142.

[1] The low values of phytoplankton off the Guañape Islands and the Lobos Islands may be due to over-cropping of the animal plankton, here in its highest concentration.

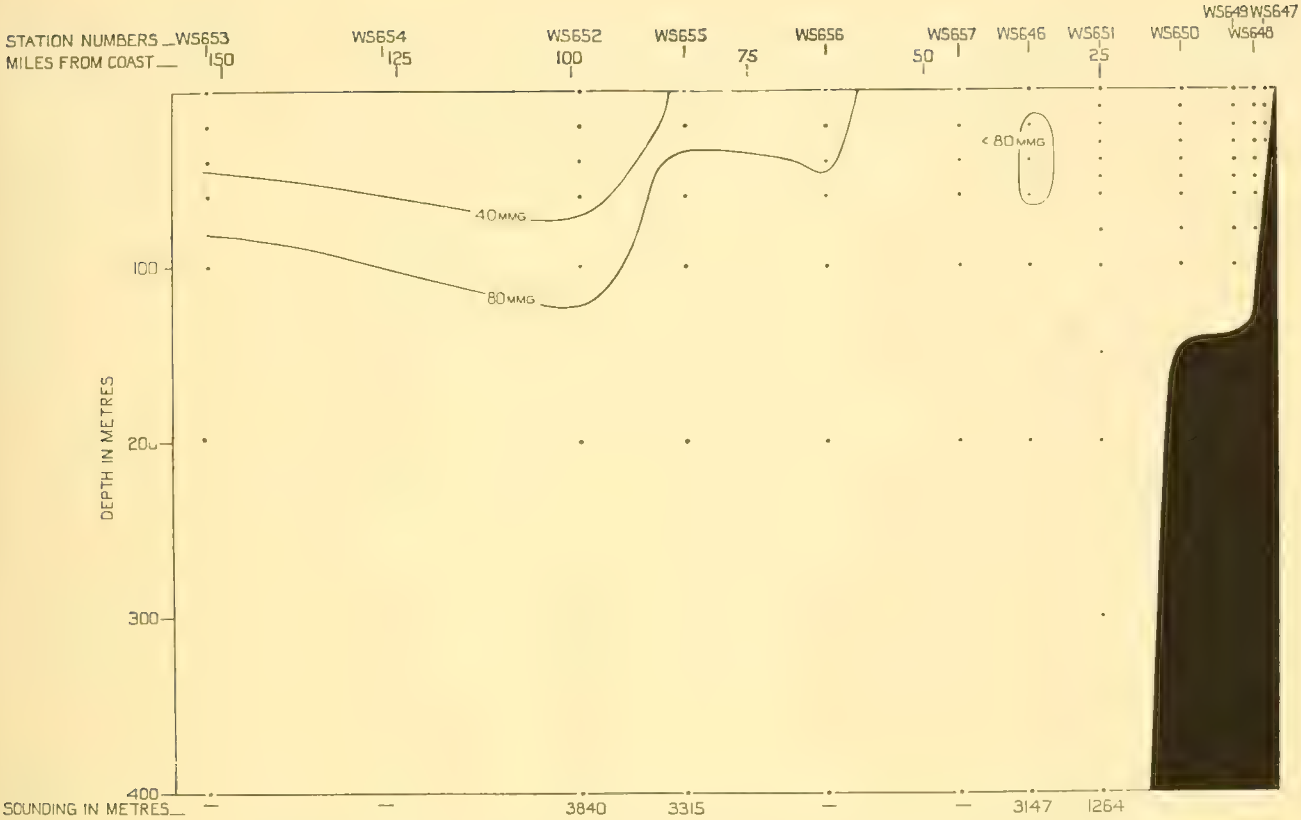

Fig. 57. Distribution of phosphate (per m.^{3}). Section off San Juan, June 22–24. Corresponding sections of temperature and salinity are illustrated in Figs. 33 and 45.

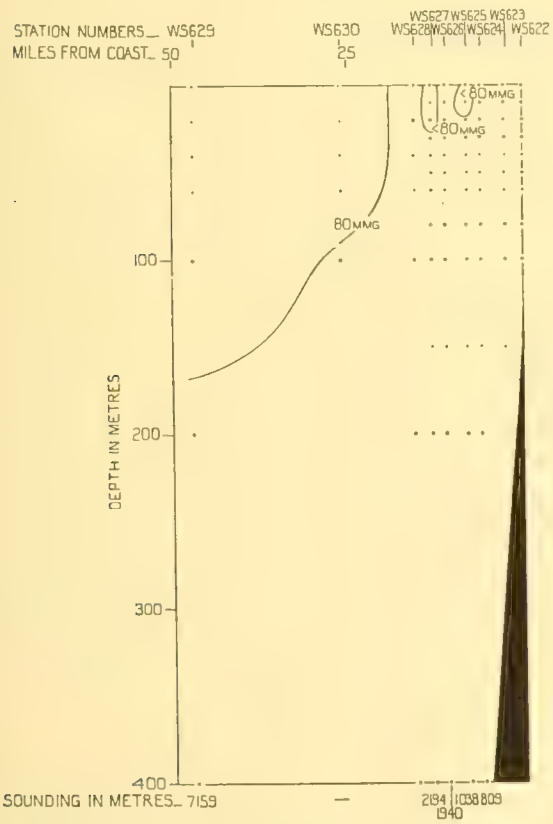

Fig. 58. Distribution of phosphate (per m.^{3}). Section off Antofagasta on the outward journey, June 8–9.

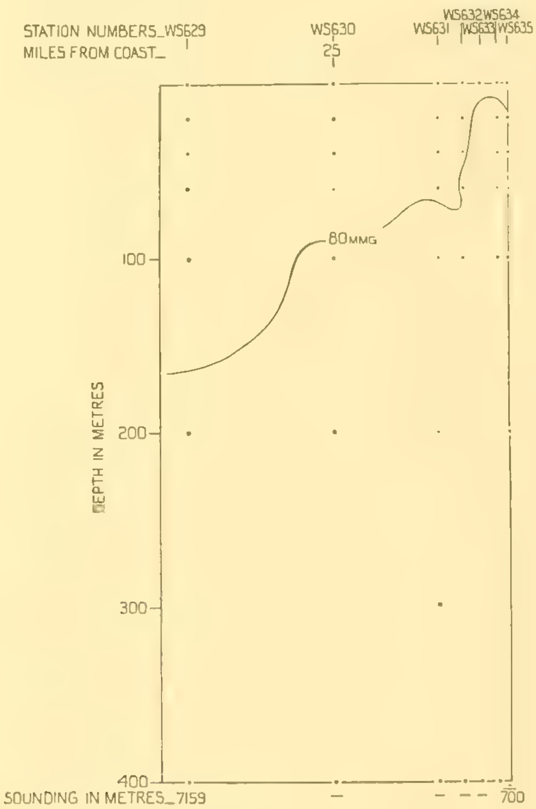

Fig. 59. Distribution of phosphate (per m.^{3}). Section off Antofagasta on the return journey, June 9–10.

Temperature and salinity sections corresponding to Figs. 58 and 59 are illustrated on p. 143.

at 80 and 100 m., for each station. These percentage values are compared with the corresponding phytoplankton catches in Table XIV. The mean of the percentage reductions for each value of the phytoplankton shows a correlation; and, if we may suppose an interrelation at some earlier date between upper and lower layers, it may be said that off Cape Carranza the volume of the phytoplankton varies inversely with available phosphate.

Table XIV. *Relation of phosphate reduction to volume of phytoplankton*

Cape Carranza				Antofagasta				San Juan			
St.	Phyto-plankton vol. c.c.	Phosphate reduction %	Phosphate reduction Mean %	St.	Phyto-plankton vol. c.c.	Phosphate reduction %	Phosphate reduction Mean %	St.	Phyto-plankton vol. c.c.	Phosphate reduction %	Phosphate reduction Mean %
592	<25	22	16·5	622	<25	5		**652**	**<25**	90	
596	<25	11		623	<25	41		**654**	**<25**	—	91
593	25	35	35	624	<25	39	32	**653**	**<25**	92	
594	75	4	18·5	629	<25	30		646	<25	0	7·5
595	75	33		630	<25	45		651	<25	15	
599	100	40	40	626	75	46	46	650	12	2	2
600	125	46	46	625	100	36	36	647	25	0	
597	150	55		627	150	47	47	648	25	0	0
598	150	50	57·3					649	25	0	
601	150	68						657	75	4	4
								655	150	66	66
								656	300	32	32

Surface phosphate is measured against the value at 100 m., and the difference, expressing reduction, is given for each station as a percentage of the latter (see text, p. 184). The stations of each line are arranged in order of increasing phytoplankton yield and for stations of similar yield the figures expressing phosphate reduction have been averaged. The figures in heavy type represent observations made in the region of the highly saline warm-water wedge. At Sts. WS 591 and 628 the 50-cm. net was not fished.

The lack of phosphate off Pichidanque Bay has been attributed to an absence of upwelling; on this line the phytoplankton is also meagre, and if the presence of thick phytoplankton is regarded as evidence of an earlier abundance of nutrient salts, its absence here indicates that upwelling has probably not taken place for some considerable time.

The small quantity of phytoplankton and the hydrological conditions agree in showing that at Caldera upwelling was of recent date. The high temperature and the minimal phosphate at the surface on the seaward part of this line makes it probable that recent conditions had been preceded by a period of prolonged calm. On the other hand, the water is homogeneous to a depth of 50 m., which is evidence that the calm period was followed by winds of a strength sufficient to cause extensive vertical mixing in the upper layers. The recent occurrence of these winds is consistent with the upwelling inshore; while the fact that upwelled phosphates were diluted and the fact that in

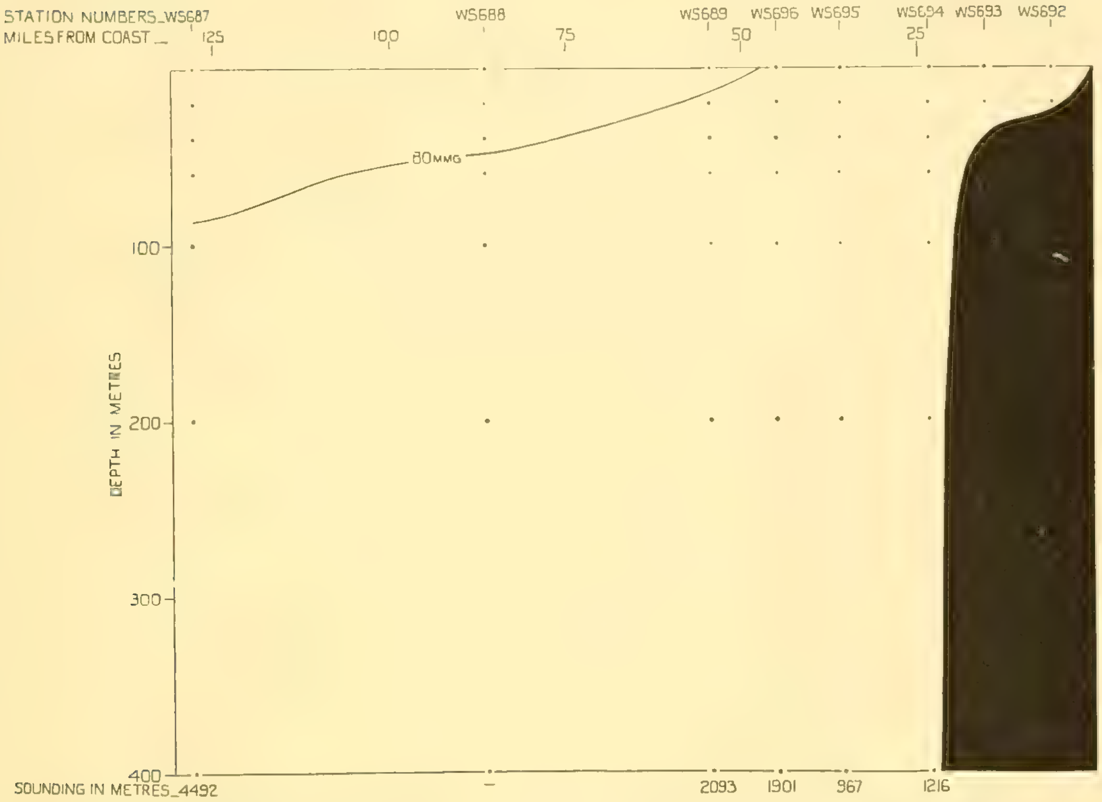

Fig. 60. Distribution of phosphate (per m.³). Section off the Lobos Islands, July 17–20.

Fig. 61. Distribution of phosphate (per m.³). Section off the Guañape Islands, July 10–11.

Temperature sections corresponding to the Figures on this page are illustrated on p. 155; salinity sections, on p. 167.

this zone phytoplankton catches were small together suggest that this upwelling is of very recent date.

At Antofagasta, a patch of phytoplankton having a high concentration was crossed in the area of cool upwelled water rich in phosphate 7–15 miles offshore. The three observations in the phytoplankton patch (Sts. WS 625–627) show a decrease in phosphate from high to medium values, whereas at the same stations at 80–100 m. phosphate values are high (Table XIV). In the poorer water offshore and in the poorer water of the second Antofagasta line, no phytoplankton patches were recognized.

In its relation to the distribution of phytoplankton, the percentage reduction in surface phosphates off San Juan conforms with the conditions met with off Cape Carranza and Antofagasta (Table XIV) except for an apparent reduction of 91 per cent at Sts. WS 652–654 in the highly saline warm-water wedge where the phytoplankton was negligible. The anomalous condition at these stations is explained if the water of the wedge has an oceanic origin and unlike surface water closer inshore has not arrived, recently at any rate, by upwelling. This suggestion receives some support from the species composing the phytoplankton: for whereas the inshore stations were rich in *Chaetoceros*, *Thalassiosira* and *Rhizosolenia*, at Sts. WS 652–654, these genera were replaced by *Planktoniella*.

In regard to the lines off northern Peru, we have unfortunately no phosphate data off Callao and Punta Aguja where alone exceptional catches of phytoplankton were made. Phytoplankton in the catches off the Guañape Islands, Lobos Islands and Capo Blanco was comparatively poor, but the nets contained a consistently rich zooplankton fauna.

These results may be summarized (Table XV and Fig. 62) by combining the data off Cape Carranza, Antofagasta and San Juan and averaging the percentage figures expressing depletion for stations of different phytoplankton concentration. The method and the results are discussed on pp. 218–19. It will have been noted that data from other lines do not lend themselves to preliminary treatment in respect of the detailed or more intimate relation between phytoplankton and phosphate, and that this is because either the phytoplankton is poor and our measurements are not representative or the phosphate data are incomplete.

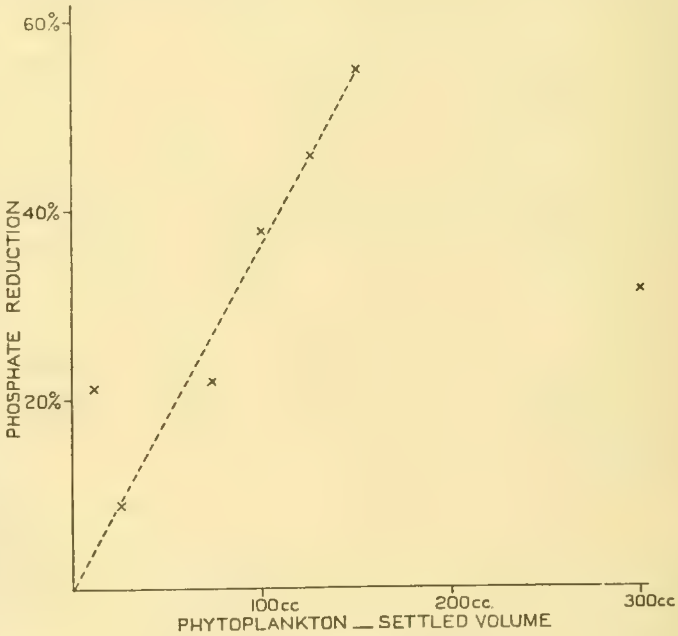

Fig. 62. Graph relating phosphate reduction to volume of phytoplankton: off Cape Carranza, Antofagasta, and San Juan. For explanation see text and Tables XIV and XV.

Table XV. *Summarized relation of phosphate reduction to volume of phytoplankton off Cape Carranza, Antofagasta and San Juan*

Phytoplankton settled vol. c.c.	No. of observations	Calculated reduction of surface phosphate (mean value) ‰	Notes
25	13	21	? reduced by zooplankton
25	4	9	
75	4	22	
100	2	38	
125	1	46	
150	5	57	
300	1	32	? value of settled volume

The data in this table are computed from the figures set forth in Table XIV. Data collected at Sts. WS 652–654 in the region of the warm-water wedge have been omitted.

CONCLUSIONS ON THE RESULTS OBTAINED

CURRENT

The surface circulation on the west coast needs to be examined more fully than has been possible on the present survey before an exhaustive account of the region can be rendered. The water-masses composing the uppermost layers share in the anticyclonic gyratory movement of the eastern South Pacific; but throughout our results run evidences of larger and smaller eddies which give rise to counter-currents of supreme importance to the coastal biology. At the surface this movement has been recorded directly by the set and drift of the ship, and indirectly by other hydrological data. Movement beneath the surface has been inferred by indirect means only.

NORTHERLY CURRENT

Surface Current. A study of the ship's drift has been made on pp. 125–133, where it was shown to be northerly at irregular intervals, greater inshore with a mean northward velocity of 10–12 miles a day than at a distance of 100–130 miles, where the mean northward velocity was only $3\frac{1}{2}$ miles a day. Seldom was there a sudden change from the zone of heavier drift to that of lesser, but the mean values over the whole coast showed a slow diminution with increasing distance from shore. Winds, on the other hand, are stronger offshore than inshore. It follows that the influence of current on the drift of the ship in a direction parallel to the coast is greatest inshore.[1] It is reported that steamers take one-tenth longer on a given run going south than going north, and that near Antofagasta fishermen find difficulty in working southwards under sail (Coker, 1918). It is of historical interest, too, that Betagh, when masquerading as a Spaniard in a prize captured off the Peruvian coast, was challenged by an enemy vessel and he used

[1] See footnote on p. 190.

plausibly the adverse current as an excuse for failing to arrive in Lima (1728, pp. 242–243). Such is the accumulated experience of navigators, but northerly current, like other currents on this coast, was pre-eminently irregular in its occurrence, a fact which will have been noted in earlier sections and which, if borne in mind, will assist interpretation of the hydrological conditions.

According to *Ocean Passages of the World* (Somerville, 1923) the speed of the current is 0–30 miles a day off Chile and 10–25 miles a day off Peru; and according to *Derrotero de la Costa del Peru* (Stiglich, 1918), the current can be neglected except in two places, along the south coast of Peru northwards of Mollendo, and between Eten and Punta Aguja. Our experience was much the same, and in this connection, the absence of current off Callao which lay between these two centres is important, and seems to be a not infrequent condition. Dinklage, while finding no current inshore at Callao, recorded westerly set offshore (Schott, 1891).

Since winds offshore are stronger, and more closely approximate to the south-east trade, the lessening of northerly current with distance from shore is probably accompanied by an increasing set towards the west. The present survey gave few opportunities of observing current other than parallel to the coast, but the universality of upwelling off both Chile and Peru is evidence that westerly set of the surface layers was in progress and was widespread. It was especially pronounced off northern Peru (Table I), the region where it is known to be characteristic (Garcia 1870, and the *South American Pilot*, 1927); and it was also recorded by us off Antofagasta in the presence of easterly and southerly wind. It was not, however, ubiquitous, and off the Lobos Islands, San Juan, and Antofagasta (return journey) easterly set was met. The circumstances in which easterly set was found suggest that it was of localized rather than of general occurrence, and that it is usually bound up with eddies (e.g. off Antofagasta see pp. 127 and 208, and off the Lobos Islands pp. 131, 164 and 220).

DEEP CURRENT. At the time of this survey, the convergence of sub-Antarctic water and subtropical water in the meridian of 71–72° W. lay in 24–26° S. Although records of surface drift give little evidence of northerly current[1] in the sub-Antarctic water, a study of salinity shows that the sub-Antarctic water extends northwards beneath the subtropical water for some 10° of latitude: this has been shown on pp. 161–2 to differ markedly from conditions in the South Atlantic where sub-Antarctic water returns southwards shortly after meeting the subtropical water. Until the flow of subsurface layers has been determined, the implication of this northerly extension of sub-Antarctic beneath subtropical water on the west coast can be put forward only tentatively. Con-

[1] In these and other data, the strength of current is obscured by the difficulty of differentiating between the effect of current and the effect of wind on the drift of a ship. Observations of current based on discrepancies in the observed and calculated position of ships are easily vitiated by the effects of wind, and windage cannot be recorded accurately because it varies daily with every ship (Lartigue, 1827, p. 21). Only a ship which had steamed across the usual direction of the current or had been able to use a current meter would have realized, for instance, the immobility of the water and the full extent of the wind met by us off Pichidanque Bay; and in view of the prevalent weakness of the current on the entire coast, it seems probable that popular belief in its strength may be exaggerated.

sideration of the fact that the surface water moves away from the coast towards the west, suggests that layers below move toward the east to compensate for the water which is welling up (Schott, 1891, p. 215): this is suggested too by isohalines in Figs. 47, 49 and 50. If this is the case, the northerly extension of sub-Antarctic water beneath subtropical water may be regarded as a mid-water current of compensation associated with the coast.

SOUTHERLY CURRENT

Surface Current. Southerly current close against the coast, to which references are very frequent in the literature, was met off Capo Blanco, Antofagasta and Caldera (Figs. 14 and 15, and Table I). Inshore of the Lobos Islands, the distribution of surface salinity suggests that a similar coastal counter-current may have been present. These counter-currents were of small dimensions and were seldom more than 2–3 miles in width; we have in consequence few data relating to them. They occurred in regions where water movement, and especially movement towards the north and west, was conspicuous and where, therefore, upwelling on a corresponding scale might be expected. In the neighbourhood of the counter-currents, however, upwelling was locally allayed and the counter-currents seem to have been in part currents of compensation. They are thus seen to constitute a series of eddies and are probably such as may be found on any coast. These eddies are cyclonic and the convergence of the counter-currents with the coast is presumably an expression of the tendency to deflect *cum sole*. At Caldera the surface drift is illustrated diagrammatically in Fig. 8, while the depth reached by an eddy-like mass of sinking water is illustrated by the section in Fig. 23.

Records of southerly drift at some distance from the coast do exist but are fewer (Frezier, 1716; Juan and Ulloa, 1748; Belcher, 1843; and Stiglich, 1925): according to Romme (1806):

> Près de cette côte, les eaux se dirigent au N, tandis qu'au large elles s'avancent vers le sud. A Arica suivent Frezier, les courans, en été, portent au N et au NO; mais en hiver, au sud. Devant Callao et dans les parages voisins, on a observé, au large, un courant dirigé au sud, tandis que le long de la côte, les eaux s'avançaient dans le nord.—A 80 lieues en mer, entre les parallèles de 15° S et la ligne, et même jusqu'à 15° N, les courans portent généralement à ouest, et ils s'avancent dans le sud, sous des latitudes plus grandes que 5° sud.

A highly saline warm-water wedge which during the present survey lay in the open ocean was well away from the coast, had a breadth of some 50 miles and seemed to extend along the greater part of the Peruvian coast; it was thus of considerable dimensions (Fig. 16). High salinity and temperature and a breadth which varied little were the distinguishing characteristics of this wedge, but southerly flow was recorded off San Juan and off northern Peru. Upon these facts, the conception of a counter-current based, though its acceptance as a continuous counter-current leaves much to be explained. Moreover, the observations in the wedge off Callao and San Juan, are separated by about 270 miles, and in this distance no data are available except close to the coast.

The continuity of the wedge from north to south cannot therefore be substantiated, and the alternative, that more than one wedge is in question, calls for examination. A comparison of the temperature and salinity sections off Callao and San Juan (Figs. 32, 33, 44 and 45) shows a similarity in the structure of the wedge off each of these localities which would be hard to explain if the water were supposed to flow from one to the other. The two localities are separated by some 270 miles. While strong southerly current was recorded in the wedge off San Juan, none was noted off Callao, and it is unlikely that in travelling this distance the temperature, salinity and general structure of the wedge could survive so little altered.

From a theoretical standpoint, also, the wedge if it experienced a flow southwards from Callao to San Juan should tend to deflect to the left and to converge with the coast, and after leaving Callao would not presumably swing to the right into the open ocean. Moreover, the presence of the warm water close inshore at Callao and Arica, and the way in which surface isotherms slope inwards towards these localities from the open sea, suggest that off Peru two wedges are involved (see Fig. 63). The serial continuity shown by salinity (Table VI, p. 161) from one wedge to the other, while it may be regarded as supporting the notion of a single counter-current, might equally be applied to the hypothesis of two counter-currents, showing them to be homologous, to be drawn from the same water mass but from different latitudes.

The two wedges are seen to lie off strips of the coast—off northern Peru and northwards of Mollendo—where northerly current and westerly set are notorious. Northerly drift and westerly set in these localities were not only noted by direct observation during the present survey, but could be inferred from the prevalence there of cool upwelled water shown in Fig. 63. The wedges flowing south-east and converging with the coast immediately to the southward of these two centres imply the existence of two large anticyclonic swirls.

According to this view, the first wedge was converging with the coast northwards of Callao to compensate, in part, for the strong current off northern Peru. Corresponding to this, the second wedge, some 5–10° of latitude farther south, also originating from the open ocean, was converging with the coast in the Bight of Arica to compensate in part for the strong current off the San Juan-Mollendo region.

Evidence of an indirect nature suggests that the swirls may be a recurrent if not a permanent feature of the coastal current. Attention has already been drawn to the fact that coastal current is traditional between Eten and Punta Aguja and in the Mollendo-San Juan region (Somerville, 1923); likewise westerly set (*South American Pilot*, 1927, Part III; Ray, 1896); attention has also been drawn to the frequent absence of current at Callao and Arica (Buchanan, 1886; Schott, 1891). Schott (1931) has shown that the former localities were foci of strong upwelling, whereas the latter were regions of high temperature in 1927 and 1929 (see pp. 214–15). In view of the conclusions reached on pp. 229–33 that the unusual colours of the sea met by us off Pisco, Callao and the Guañape Islands were a form of *aguaje* and may have been a result of the convergence of the wedge with the coastal water, the appearance of *aguaje* during winter months described

Fig. 63. Distribution of surface isotherms off Peru, June to August, 1931; as suggested by the evidence for two warm wedges. The probable existence of two anticyclonic swirls is indicated by the currents, represented in the figure by arrows.

by Raimondi (1891), Lavalle (1924) and Stiglich (1925) might be regarded as due to the same cause and as evidence of the recurrent nature of these swirls.

Clowes (1933) distinguishes between stationary whirls[1] such as may be dependent upon the topographic features of the sea-bottom, and whirls which are not stationary such as the travelling disturbances that may be met with along a convergence.

The evidence just reviewed suggests that the anticyclonic swirls off the Peruvian coast have a stationary character. While this may be approximately true, data collected during the survey point to the probability that the more northerly wedge was first converging with the coast southwards of Callao, but later northwards of Callao. In this way it is thought that the isolated patch of very warm water of 19·10° C. in Pisco Harbour (Appendix IV) and the changes of temperature off Palominos Island (Fig. 51) and off the Guañape Islands might be explained (see pp. 208–9). Alterations in the size or position of the swirl would bring about these changes; and as no direct connection with the sea-bottom is apparent, an oscillation in the position of the swirl, possibly with changes in the meteorological conditions, may be expected.

It remains to refer to the easterly and southerly drift of the Prussian sloop 'Mentor' in 1823. Mentor's Gegen Drift, as it was distinguished by Berghaus on his chart of 1837, is marked as setting towards the Bight of Arica; but since it was recorded in approximately 20° 13′ S, 83° 07′ W (Berghaus, 1842), which is at some considerable distance from the Peruvian coast, its identity with the wedge met with during the present survey must remain in doubt.

Deep Current. Another current of importance proceeding towards the south is the return current off Chile flowing between sub-Antarctic water and the Antarctic intermediate water. Having a northerly origin, it is distinguished from these two by a higher salinity, warmth and poor oxygen content: it seems to be derived from both subtropical and sub-Antarctic water. The influence of the earth's rotation may perhaps be seen in its convergence with the coast, and is, moreover, seen in Figs. 18, 20, 22, 24 and 45 to be a purely coastal phenomenon. This suggests that it may be, like the extension northward of sub-Antarctic water, a mid-water current compensating for the water which is welling up. But whereas the sub-Antarctic water above it is frequently to be found drawn to the surface, this return current, lying below, was found to be welling up only at San Juan and Antofagasta, areas of exceptional upwelling.

The various current systems that are shown above to be an adjunct of the Peru Coastal Current, probably each exert an important influence on the fauna and flora. The possible influence of the eddy is discussed on p. 220. The return current just described, whose oxygen has been reduced by the rich life of the inshore waters, may be returning organisms and their spores towards the south after they have been carried away northward at the surface. The northward extension of sub-Antarctic water brings water rich

[1] Clowes (1933) refers to a gyratory movement in the Weddell Sea by the term "whirl". The present writer has taken the term "swirl" from Tait (1930).

in nutrient salts, and the process of mixture with the other layers may be a factor of importance in the high productivity of these waters.

ORIGIN OF THE COOL WATER

The probability that cool water reaches the surface close inshore by upwelling was inferred by de Tessan (1844), by Dinklage in 1874, by Witte (1880), Hollmann (1882), Hoffmann (1884) and Buchanan (1886), because the explanation advanced by Humboldt (1811) of a cool surface current from high latitudes was obviously untenable. As a result of Duperrey's observations (1831), the adherents to Humboldt's theory claimed for the current a polar origin, but Bougainville (1837) showed that the water would warm up if it flowed through so many degrees of latitude. Though the upwelling explanation has hitherto rested on indirect evidence it is accepted by the majority of modern writers, but Thoulet (1928), working upon data collected by the Challenger Expedition on her passage from Tahiti to Valparaiso, attributes the cool water to melted snow carried down by rivers from the Cordillera; and Wüst (1935), apparently viewing the subject from a nationalistic angle, makes enhanced claims for Humboldt's theory.

Three principal views have been expressed on the causes of upwelling. Dinklage (Schott, 1891, p. 215) maintained that the inshore waters were drawn away from the coast by aspiration as a result of the action of the trade winds in the open ocean (*vide* his observation on current at Callao); and Witte (1880), on theoretical grounds, maintained that upwelling would result either by the action of the earth's rotation upon meridianal current such as this, or by the action of winds blowing off the coast. Buchanan (1886) tried to establish the latter of these views on the theory of "Trade Belts". On this coast, however, winds do not blow off the shore but parallel to it; and the theory of "Trade Belts" has long given place to the theory of high-pressure centres. Thus Buchanan's explanation is easily disproved.

The present work confirms the views already expressed by Schott, and reference to Figs. 18–61 can leave little doubt that, as a result of wind acting in conjunction with forces due to the earth's rotation, the subsurface layers were upwelling or had been upwelling in every one of the twelve localities examined between Cape Carranza and Punta Aguja.

Widespread lowering of temperature in the Peru Current is to be expected as a result of its flow from cooler to warmer latitudes; and cooling by this means must happen in accordance with oceanographical principles: but consideration of the temperature and current data suggest that this process is secondary in importance to cooling by upwelled water.

The charts of surface temperature (Figs. 16 and 17) and the temperature curves in Figs. 34 and 66 reveal isolated patches of cool water off Payta, Puerto Chicama, San Juan, Iquique, Antofagasta and probably Caldera, which cannot easily be explained in terms of northerly transport. These are clearly instances where upwelling has modified the orientation of surface isotherms. The influence of upwelling may be supposed to be

more far-reaching than this, since the low temperatures of recently upwelled water are continually dissipated by admixture with its surroundings.

Inshore current, wherever it occurs, must be a factor of importance in carrying low temperatures northward: but the evidence examined on pp. 125 to 133 and on p. 190 shows that northerly current is not only irregular but that the inshore water is more often than not setting towards the west; and that drift in the open ocean is predominantly west. Low temperatures near the coast would thus appear to be continually borne off towards the west, and to be replaced by further upwelling. In this respect, the Peru Current differs from a current like the Labrador Current which, converging with the American coast, is probably able to carry water particles and a low temperature for almost the entire length of its course.

COASTAL UPWELLING

ESTIMATION OF UPWELLING

In order to compare upwelling in different localities, it is first necessary to find a method of estimating its degree. The method most used has consisted in noting the reduction of surface temperature as compared with an arbitrary standard. McEwen (1912), in his investigations of upwelling off California, selects as his standard the thermal normal for the latitude, which he assumes (p. 261) "is the same as the actual temperature at a point in mid-ocean having the same latitude". Thus the difference between the observed temperature and the normal temperature is assumed to be due entirely to the mixture of cold water from the adjacent ocean bottom with the surface water. The disadvantage of adopting this as the thermal normal for the latitude has in part been shown by McEwen himself in a remark on p. 244 to the effect that "The question of the distribution of temperatures in the sea is so intimately connected with that of the character of its currents that it is practically impossible to separate them entirely".

Schott (1931) uses as his standard the mean surface temperature at a distance of 100 miles offshore. This has the advantage that both the temperature here and close inshore will be subject to the same local major variations: but it is open to the criticism that at this distance from shore the temperatures are influenced by upwelling off Peru where the surface isotherms are far apart to a greater extent than off Chile where isotherms tend to hug the coast. The effect is an apparent reduction in the amount of upwelling off Peru, because the contrast between inshore and offshore temperatures is reduced. This is seen by comparing the surface temperature inshore with that at 46 miles offshore both at Caldera and San Juan. Off Caldera the difference was 3·36° C., off San Juan only 1·46° C.; yet more upwelling seemed in progress off San Juan, for here a greater volume of cool water was present inshore, and the difference between the temperatures inshore and at 152 miles offshore was 5·0° C.[1]

[1] It is interesting that this effect happens to be largely neutralized by another factor working in the opposite direction—namely the greater difference, in the tropics, between surface and subsurface temperatures than in higher latitudes. The net effect is to give Schott's curve a slope tolerably close to the standard we have chosen.

The standard adopted by both these writers consists of a series of surface temperatures more or less representative of the thermal normal at the surface. With this "normal" is compared the temperature reduction caused by upwelling of lower layers. This method may be applicable to measurement of upwelling in one place at different times but not to measurement of upwelling in different latitudes; for at the surface, temperature has a wider range from high latitudes to low than in the depths from which upwelling waters originate. There may be a difference of two or three degrees between the surface and 150 m. in lat. 40° S, but a difference of ten at the equator. Judged by this method the same amount of upwelling would produce a more conspicuous fall of temperature in the lower latitude. *Vice versa*, adoption of the thermal normal at the upwelling depth is equally unsuitable.

To meet this difficulty a standard has been sought which is in some way related to the waters inshore. These are essentially a mixture of the deeper waters with those at the surface. If we knew the ratios in which these two mixed and we knew their respective initial temperatures it would be a simple matter to calculate a mean resultant temperature and this could be used as a standard. As we do not know these facts, we have endeavoured to construct an approximately similar curve by averaging the surface temperatures outside the area of upwelling, e.g. say in 100° W, with the temperatures at the mean depth of upwelling, e.g. say 150 m.

In Fig. 64 the inshore surface temperatures as observed from Cape Carranza to Capo Blanco (curve D)[1] are compared with temperatures observed at a depth of 150 m. on the one hand (curve A and the interpolated values A')[2] and on the other with the mean surface temperatures in the ocean in the meridian of 100° W (curve C)[3]. The slope of the curve D is seen to differ from curves C and A' but lies somewhere between them. If, as the result of upwelling, water represented by curve A' mixed in equal volumes with water represented by curve C, the resulting temperature could be represented by the curve $\frac{A'+C}{2}$. But if the mean upwelling depth lay above or below 150 m., and if upwelling water mixed with water cooler or warmer than that at 100° W, or again if more of one mixed with less of the other, then the resulting temperatures would of course depart from those shown by the curve $\frac{A'+C}{2}$. A curve of this type should enable a better comparison to be made than hitherto of the amount of upwelling in different latitudes, though it will not afford a measurement of the absolute degree of upwelling at any one place.

DEPTH AFFECTED BY UPWELLING AND WATER LAYERS INVOLVED

Earlier writers have been handicapped by lack of observations beneath the surface, and those who first advanced arguments in favour of upwelling on this coast, made no reference to the depth of water likely to be affected. Upwelling of polar-fed bottom water was implied by Coker (1918) and Murphy (1923), but Sverdrup (1931) has shown

[1] See Table XVII. [2] See columns A and A', Table XVI. [3] See column C, Table XVI.

that the Antarctic intermediate layer can be recognized intact in the stations taken by the 'Carnegie' near the coast. The isotherm of 10° C. is found at a uniform depth of about 320–340 m., both in mid-ocean and near land. As no vertical movement of water

Table XVI. *Measurement of upwelling. Data used in constructing a standard curve to which inshore surface temperatures in different latitudes may be compared*

Locality	Latitude ° S	Temperature observations at 150 m. offshore				Mean surface temperature in 100° W	Standard temperature
		St. No. WS	° C.	Mean			
				A	A'	C	$\frac{A'+C}{2}$
Cape Carranza	40	—	—	—	—	14·6	—
	35	600	10·40	10·51	10·2	17·1	13·65
		601	10·62				
Pichidanque Bay	32	606	10·52	10·56	10·7	18·7	14·7
		607	10·60				
	30	—	—	—	—	19·5	—
Caldera	27	619	**11·20**	11·83	11·3	20·5	15·9
		612	11·83				
Antofagasta	23	630	11·65	11·28	11·9	21·4	16·65
		629	10·92				
	20	—	—	—	—	22·3	—
Arica	19	639	12·56	12·56	12·4	22·3	17·35
		638	12·56				
San Juan	15	654	11·98	12·14	13·0	22·8	17·9
		653	12·31				
Callao (July)	12	669	13·03	12·98	13·4	23·2	18·3
		668	12·94				
	10	—	—	—	—	23·3	—
Guañape Islands	8	686	14·53	14·53	13·9	23·3	18·6
Lobos Islands	6	688	13·51	13·62	14·2	23·3	18·75
		687	13·74				
Punto Aguja	5	706	14·21	14·00	14·3	23·3	18·8
		707	13·80				
Capo Blanco	4	708	**14·60**	15·02	14·5	23·3	18·85
		722	15·02				
Santa Elena	2	718	14·79	14·77	14·8	23·2	18·95
		719	14·76				
	0	—	—	—	—	23·0	—

Note. Data in heavy type appear to have been unduly influenced by upwelling and have been omitted from reckoning.

Figures in column A represent means of the original data given in the preceding column (unpaired data excepted) and are plotted in curve A', Fig. 64.

Figures in column A' were obtained from curve A', Fig. 64, by interpolation.

Figures in column C are taken from Schott and Schu and include interpolated values, see curve C, Fig. 64.

The standard temperature is the mean of A' and C.

can take place without disturbing natural stratification, he argues that the extreme depth likely to be affected by upwelling is 300 m. Schott (1931) associates himself with this conclusion.

The water layers which are drawn upwards or which reach the surface as a result of upwelling are shown in the sections illustrating salinity, pp. 138–143 and pp. 164–169. South of the subtropical convergence, upwelling involved two water layers; sub-Antarctic water coming to the surface, and the return current beneath showing upward

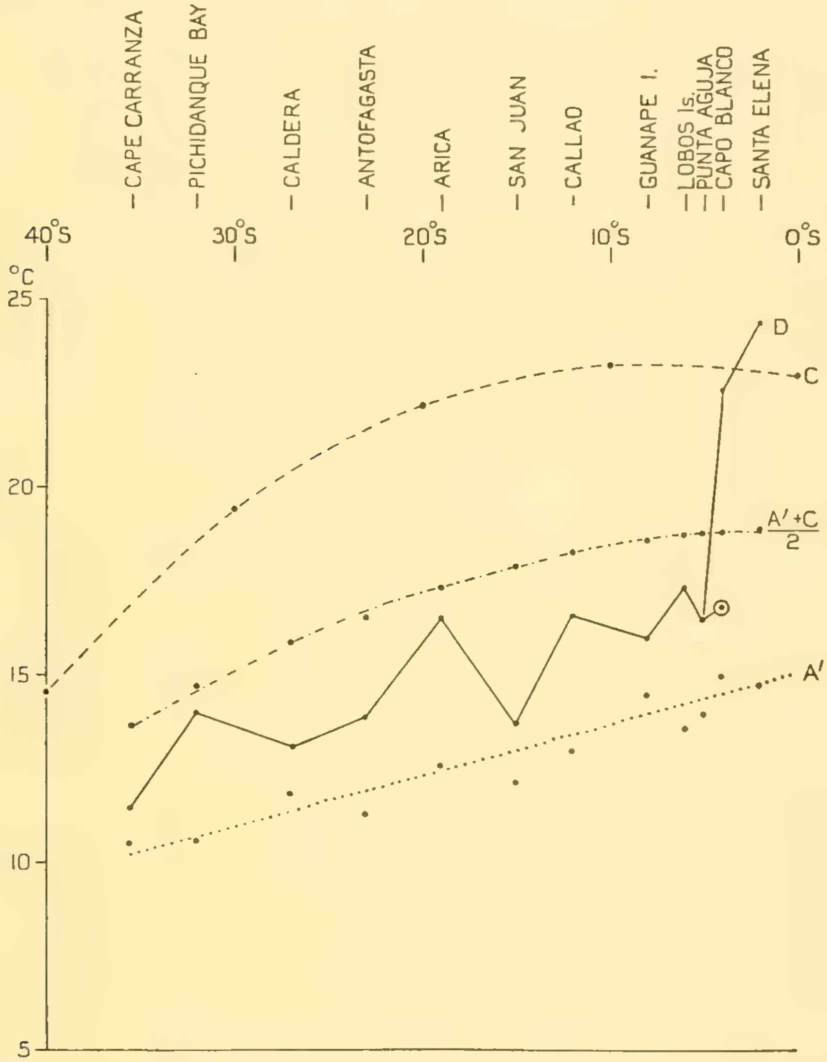

Fig. 64. Measurement of upwelling. Comparison of inshore surface temperatures (curve D) with temperatures at a depth of 150 m. outside the upwelling zone (curve A'); with surface temperatures offshore in 100° W long. (curve C): and with the mean of the two latter, $\left(\text{curve } \frac{A'+C}{2}\right)$. For explanation see text and Table XVI.

Note. The record marked ⊙ in curve D represents the temperature of upwelled water in the Peru Current, but was obtained at 35 miles from shore. The high temperature inshore represents the Equatorial Counter-current and is not upwelled water (cf. Figs. 41 and 70).

movement: only at Cape Carranza (Fig. 18) was the latter drawn at all close to the surface. North of the subtropical convergence, upwelling involved as many as three layers. The return current featured at the surface at two localities at Antofagasta and San Juan, where upwelling was unusually strong, and sub-Antarctic water appeared

at the surface at Arica, where it was still recognizable as a distinct layer; elsewhere upwelling occurred solely within subtropical water. Thus the Antarctic intermediate water was never touched.

An accurate idea of the depths affected by upwelling is not easily obtained, because the return current, hugging the coast in the upwelling depths, interferes with the normal trend of isotherms and isohalines. The coastal character of the return current is suggested not only by our sections, but by the fact that no evidence of it can be found in the section representing the 'Carnegie's' oceanic stations 60–70. Its shape in section is roughly that of an elongated isosceles triangle lying on its side. The base is flattened against the coast, the apex projects into the open ocean between the sub-Antarctic layer above and the Antarctic intermediate layer beneath. Thus its upper margin slopes upwards towards the shore. This upward slope might be accounted for partly by upwelling, but the possibility of a centrifugal effect as the current pressing to the left, presses against the coast on its southward flow should not perhaps be excluded. At Pichidanque Bay, where upwelling was minimal, the upper margin of the return current sloped inwards and upwards from a depth of about 160 m. out to sea to less than 50 m. inshore. Where upwelling was more vigorous the upper margin had a steeper slope. Thus the trend of isohalines in the Figures illustrated on pp. 138–169 while reflecting the influence of upwelling, is partly determined by the structure of the layers.

In view of the interest taken in the depth affected by upwelling, it will be appropriate to estimate the depths likely to be involved. On the evidence of isotherms, Figs. 19–41 suggest that upwelling is usually restricted to the upper 200 m., but off Callao in August, and off Caldera, depths of 280 and 320 m. appear to be disturbed. The evidence of salinity (Figs. 18–50 on pp. 138–43 and 164–9), which is perhaps more reliable, suggests that depths exceeding 200 m. are very rarely disturbed. In Table XVII a minimum and maximum estimate of the depth affected by upwelling at each locality have been listed: and the estimates based on salinity have been plotted as curves on the salinity section in Fig. 42. The minimum depth from which water wells up may be taken as the depth offshore at which salinity values are found to correspond with the surface inshore salinity. But as alteration of its salinity is inevitable in upwelling water through its admixture with the surrounding water layers, the depth from which it arises must be greater than that represented by the minimum chosen. At localities where mixture may have been extensive, a better guide to the upwelling depth might be furnished by inspection of the isohalines in Figs. 18–50. The maximum estimates in Table XVII have been obtained by this method and are plotted in Fig. 42 as a broken line.

In five of the localities—Cape Carranza, Antofagasta, Arica, San Juan and the Guañape Islands—the minimum and maximum depths so estimated correspond with fair precision within 20 m. or so of one another. At these localities the upwelling process may be supposed to be at its height and to be attended by comparatively little mixing. On the other hand, at Pichidanque Bay, Caldera, Callao, the Lobos Islands and Punta Aguja, where discrepancy is shown between these estimates of minimum and maximum

depth, the minimum estimate may have been unduly lowered through mixture of the upwelled water with its surroundings. This is shown to be probable by consideration of the state of the hydrological conditions antecedent to our visit. Pichidanque Bay has been shown to be a locality where upwelling had not been active for some time; and at Caldera mixing on a considerable scale would have been a natural consequence of the eddy and the changes of wind noted on pp. 125–7. At Callao, upwelling was not only allayed, but the inshore water might have been subsiding (p. 209). At these localities the discrepancy between the minimum and maximum estimates may imply a capacity for greater upwelling than was observed at the time of our visit. The homogeneity of the upper layers off the Lobos Islands and Punta Aguja is also evidence that mixture had been extensive, but whether at these localities upwelling was not at its height, is uncertain. Thus we see that different depths are affected according to circumstances. Upwelling brings up water from a depth of 40 m. at least, and more usually 100–130 m., and depths of 180–360 m. may sometimes be touched (Table XVII). If the figures are averaged, the mean upwelling depth is shown to be by temperature 123 m., and by salinity 143 m., themselves giving a mean of 133 m. The mean minimum and mean maximum upwelling depths are given in the table.

Table XVII. *Showing the estimated depth from which water wells up and the greatest depth affected by upwelling*

Character of surface water offshore	Length of line (miles)	Depth affected by upwelling as shown by isohalines and isotherms (metres): Minimum, Salinity	Minimum, Temp.	Maximum, Salinity	Maximum, Temp.	Upwelled water at surface inshore: Layer	Temp. °C.	Locality
	110	40	40	360	200	Sub-tropical	16·83*	Capo Blanco
	204	126	60	196	100	,,	16·50	Punta Aguja
	128	120	80	160	150	,,	17·38	Lobos Islands
	110	130	80	130	140	,,	16·00	Guañape Islands
Sub-tropical	155	100	80	100	280	,,	15·73	Callao (August)
	103	40	40	180	100	,,	16·61	Callao (July)
	152	160	90	160	160	Return Current	13·79	San Juan
	53	80	50	100	110	Sub-Antarctic	16·57	Arica
	47	188	90	200	200	Return Current	13·93	Antofagasta
	56	108	80	180	320	Sub-Antarctic	13·10	Caldera
Sub-Antarctic	129	118	40	210	180	,,	14·02	Pichidanque Bay
	83	128	70	136	200	,,	11·45	Cape Carranza
Mean		112	67	175	178			
Mean		89		177				
Mean		133						

* This temperature was at 30 miles offshore. Inshore temperature in Equatorial Counter-current was 22·62° C.

143 m. = mean depth of upwelling according to salinity.
123 m. = mean depth of upwelling according to temperature.

The minimum depth from which water wells up is judged by the depth offshore of the isotherm (and isohaline) corresponding to the value of the inshore temperature (or salinity) at the surface. The maximum depth affected by upwelling is judged by the greatest depth at which isohalines and isotherms show signs of rising up towards the shore from their normal depth.

The breadth of the zone of actual uprising is extremely narrow compared with the breadth of the zone influenced by upwelled water, but upwelling does not always seem to be in immediate contact with the coast. The breadth of the region of upwelling may be placed variously from 5 miles at Punta Aguja to may be as much as 30 miles offshore near the Guañape Islands (Figs. 35 and 37). An example of upwelling at some distance from shore was found at Antofagasta (Figs. 26 and 28) and possibly also at Pichidanque Bay and at Capo Blanco (Figs 21 and 41). At Capo Blanco a small patch of water of less than 17° C. was crossed at a distance of 31–35 miles from shore; it had a breadth of 4 miles and lay between the tongue of the Equatorial Counter-current inshore and water of the Peru Current south and west. In this area of mixing and of local eddies it would be interesting to know whether this cool water had come to the surface as the result of an eddy in the open sea or had its origin under the coast farther to the southward (see also reference to Schott's divergence line, p. 228).

Indirect upwelling by a process of vertical mixing is to be expected not only in the zone of actual uprising but for many miles westward wherever wind is heavy and the thermocline not too pronounced (Atkins, 1924), and this adds to the problem of determining the limit of the zone of actual uprising.

EFFECT OF DIRECTION OF COAST-LINE

Hydrologists have demonstrated by theory (Ekman, 1905) and experiment (Sandström, 1919) the principles that underlie upwelling phenomena, but as Ekman has himself stated, conditions in the sea are so complicated that it is impossible to calculate exactly the motions of the ocean. He has therefore taken a number of type problems in which some factors as they occur in nature—such as the shape of the ocean basin, the winds and the distribution of temperature and salinity—have been replaced by simplified imaginary ones. The principles Ekman has demonstrated may be regarded as tendencies which sea water in movement will show under various conditions: but conditions in the sea differ so materially from those postulated in the type problems that any comparison between Ekman's theories and our findings should be drawn with caution. Sandström has emphasized the dynamic importance of isosteric surfaces across which movement of the water is checked but along which it is facilitated. This report does not seek to detail water movements beneath the surface with exactitude, and the isosteric surfaces are not determined. The west coast of South America presents a number of problems, and various suggestions have been put forward to explain them. It is not inappropriate to discuss some of these in the light of the results obtained.

After remarking that in 1927 and 1929 the depression of temperature proper to the Peru Current is greater off Peru than off Chile, Schott states that the boundary between the two regions lies near Arica, that is where the coast bends suddenly. He states further that during the 'Emden's' cruise this boundary was particularly well marked; with high (normal) temperature and high salinity upwelling seems to have been nearly or quite absent. His explanation runs as follows: "Es muss hier infolge der veränderten Küstenrichtung für eine grössere oder kleinere Strecke die Stromrichtung zum Land

hin oder parallel zu ihm, aber nicht vom Land weg gehen und damit die Voraussetzung für das Aufquellen von Tiefenwasser wegfallen" (p. 168). In support of his statement, Schott brings forward the similarity between the temperature records of the two ships 'Emden' and 'Nitocris': these agree in showing that Arica lies in a region where the inshore temperature approximates closely to that 100 miles offshore.

In July 1931, conditions were markedly different; offshore temperatures being higher and inshore temperatures lower than those given by Schott. While it is true therefore that high temperatures were very close inshore, upwelling was also in active operation. The ship's drift in a direction more or less parallel to the coast gave no hint of convergence within a few miles of the shore in the Bight of Arica, the region where convergence might be most expected (see Fig. 11). The paradoxical conclusion is irresistible that some divergence from the coast was taking place in a region of convergence.

The differences between Schott's data and our own might be explained by the variable nature of the current or by differences in the type of observations made. The 'Emden' and the 'Nitocris' steamed along the current at an unspecified distance from the shore, whereas the 'William Scoresby' steamed across the direction of the current and observations were possible at various distances from the coast. The curves plotted by Schott resemble most the curve plotted by us in Fig. 34 for 2–5 miles from the shore, and as the cool water at Arica occupied a very narrow band, it is possible that Schott's data were collected outside the zone of upwelling.

Murphy (1925), who knows the coast well, contributes some remarks upon the coast-line. On p. 175 he states: "The coast of Peru... trending sharply to westward from near the Chilean border, extends far into the ideal course of the Humboldt Current, and forces the latter to become an actively impinging stream until it has passed the end of the continental buffer at Point Parina." The data collected on the present survey bears out Schott's statement that the west coast constitutes a single-sided divergence line; the Peru current cannot therefore constitute an actively impinging stream. It will be shown later (pp. 208–13) that impingement, or convergence, leads to a reduction or cessation of upwelling.

Trend of coast-line would probably rank as an important factor governing the hydrological conditions if the winds off the Chilean and the Peruvian coast were similar. But off Chile winds are predominantly southerly and off Peru south-easterly (Fig. 4). Off both coasts they are therefore parallel with the shore: and although the change in the coast-line trend may alter some aspects of the current, it seems to have a relatively minor influence upon the degree of upwelling.

EFFECT OF SEA-BOTTOM CONTOUR

McEwen (1916), describing the horizontal distribution of temperature along the west coast of North America, writes: "Upwelling of cold bottom water appears to be the only type of circulation that could produce such a distribution of temperatures. Furthermore, the contour maps (pls. 1–3) reveal a striking correlation between the location of

these areas of cold water and the submerged valleys or other regions in which the depth increases rapidly with increasing distance from the coast. For example, the cold areas north of Point Dune are close to two submerged valleys as shown by the one hundred and the five hundred meter contours."

To ascertain the effect of the bottom topography off Peru and Chile, the sections illustrated in Figs. 18–41 may be arranged according to the mean gradient of the continental shelf which is assumed to end at the point where the slope suddenly becomes steeper. As will be seen from Table XVIII, little correlation can be made out between this gradient and depression of surface temperature.

The Chilean and Peruvian coasts are not directly comparable and have been listed separately. Off Peru water is not only more homogeneous, but the shelf is much broader than off Chile, and the area of shelf whose depth is less than two and a half times Ekman's "Upper depth of frictional influence" ($2 \cdot 5 D'$) is more extensive off Peru than off Chile. Off Peru, D' would work out at about 150 m. for homogeneous water, whereas off Chile, owing to weaker wind and higher latitude, the depth would work out at about 70 m.

On these grounds one might have expected the restraining influence of the coast upon divergence of surface current to be less and upwelling to be greater off Chile than off Peru: the fact that it does not appear to be so suggests that other factors are also of importance.

Conditions within a mile or two of the beach were not explored very thoroughly. Although irregularities of the bottom contour might influence upwelling more here than out to sea, the zone is probably too narrow to have far-reaching effects upon the current as a whole. Moreover, upwelling in this zone was frequently interrupted by countercurrents. The data collected on this survey afford no support to the suggestions of Murphy (1925, p. 162) or McEwen (1912, p. 272).

Table XVIII. *Depression of inshore surface temperature at different localities arranged according to the gradient of the sea bottom in the upwelling region*

Chile			Peru		
Locality	Gradient of continental shelf	Depression of surface temperature ° C.	Locality	Gradient of continental shelf	Depression of surface temperature ° C.
Cape Carranza	1 : 180	2·20	Guañape Islands	1 : 800	2·60
Arica	1 : 120	0·78	Lobos Islands	1 : 580	1·37
Pichidanque Bay	1 : 40	0·68	Callao	1 : 190	1·69
Antofagasta	1 : 30	2·72	San Juan	1 : 160	4·11
Caldera	1 : 20	2·80	Capo Blanco	1 : 100	2·02*
			Punta Aguja	1 : 70	2·30

* The depression of surface temperature off Capo Blanco has reference to a record of 16·84° C. at 31–35 miles offshore, the coolest temperature beyond the water of the Equatorial Counter-current.

The line off Cape Carranza was situated south of the Juan Fernandez Rise, the others to the north. Comparison of the upper 300 m., within which the upwelling zone lies, shows no essential difference between the conditions off Cape Carranza and those off other localities. The suggestion (Murphy, 1923, p. 67) that the commencement of the Coastal Current may be determined by the Juan Fernandez Rise cannot therefore be entertained.

In view of the interest attaching to the possible influence of any island group upon upwelling, a special investigation of the Lobos Islands was made (see pp. 131, 153 and Fig. 12). A line of stations was run both to the leeward and the windward of the Lobos de Afuera and the isotherms at all depths from both lines were compared. Isotherms north-west of the islands (i.e. off their sheltered side) showed traces of upwelling in the upper 150 m., the isotherms of 15°, 16° and 17° showing a distinct hump in the vicinity of the rocks, whereas on the south side, the exposed side of the islands, the isotherms showed no disturbance. Signs of upwelling were, however, scarcely detected at the surface (see Figs. 30 and 12); in the latter, the isotherm of 18° C. is seen to run between the two archipelagoes, and since this direction is more or less parallel to the coast-line, nothing unusual is shown. According to the data given by Murphy (1923), in January 1920 the isotherms of 19 and 20° C. close together took an almost identical direction.

Evidence of upwelling is, however, given by phosphate in the upper 60 m. In Table XIX the data are averaged in the upper and lower layers in each of four regions. Sts. WS 690 and 691 on the one hand, and Sts. WS 696 and 695 on the other, are at roughly similar distances from the coast, but the first are off the exposed (south and south-east) and the second off the sheltered (north and north-west) shore of the islands. At the former, phosphate values were intermediate between those at shoreward and seaward stations—a normal condition. At the latter, phosphate was as high as closer inshore where upwelling occurs. Thus phosphate was richer off the sheltered than off the exposed shores of the islands.

EFFECT OF WIND

The facts collected during the present survey suggest that upwelling may be caused both by local and by remote winds. Conclusions on the effect of local wind are drawn in regions where a change in the wind was followed by changes in hydrological conditions. Winds at a distance are also supposed to be a cause, since upwelling was found at every locality examined and in meteorological and hydrological conditions which locally looked the reverse of favourable to it.

Schott (1931) has described the distribution of barometric pressure in its relation, on the one hand, to a northerly current with upwelling, and, on the other, to a reversal of the current with an invasion of the coast by hot equatorial water known as *El Niño*. Under normal conditions the south-east trades blow northwards towards a region of low pressure at the meteorological equator. In their passage along the Peruvian coast they impart a dry climate and they give rise to the currents conducive to upwelling and so are the cause of cool inshore temperatures. It frequently happens, however, that

from January to April, when the trough of low pressure usually associated with regions north of the Equator shifts southwards, there follows a complete change of wind: the south-east trades give place to winds from the north; while north-east trades from the Atlantic blow with increased strength over the Gulf of Panama and enter the South American Continent as north-west winds. These are monsoon winds and bring torrential rains to a district whose mean annual rainfall is normally less than half an inch. A southerly flow of equatorial water from the Gulf of Panama converges with the Peruvian coast, sometimes reaching as far south as Callao and Pisco, and it raises the inshore temperature by as much as 10°. The consequences of this to marine life have frequently been described. But of immediate interest is the simultaneous appearance of upwelling off the inner part of the Gulf of Panama. During these few weeks the coast in the Gulf of Panama has the characteristics of a windward shore and upwelling results. Thus in a region usually bathed by the light hot water of the Equatorial Counter-current, a region characterized by conditions which are usually the antithesis of upwelling on account of the convergence of the current with the coast and the steep thermocline in the upper layers, a cold current is found welling up and flowing southwards in the wake of *El Niño*, and reaching sometimes at least as far south as the Equator. Schott has already emphasized the interest of this in dynamic oceanography by pointing out the correspondence between periodical rises and falls of temperature in the Gulf of Panama with inverse falling and rising of temperature in the *Niño* region, and the fall and rise of temperature in this region with barometric oscillations at Puerto Chicama.

Serial records over a number of years at two or three coastal stations make these correlations possible. Such opportunity is denied to a ship on a brief cruise, but we were able to record changes in hydrological conditions apparently following changes of wind in three localities. At all of them upwelling was increased in the presence of winds from the east and south but diminished in the presence of winds from the west and north. Other factors were different in each of the localities, which must therefore be examined individually.

Antofagasta

The change in temperature conditions at Antofagasta, both at the surface and beneath it, has been noted on pp. 141–5, and parallel changes in the sections illustrating phosphate content on pp. 182 and 185. It was shown that on steaming out from the shore strong easterly and southerly winds were blowing, and the temperature indicated an active state of upwelling: phosphates at the surface were rich (Figs. 26–28 and 58, 59). On the return journey the wind had changed to the north, and both cool water and rich phosphates had vanished from the surface; that is to say, surface isotherms were found closer to the coast (Fig. 28).

Several mechanisms may have been acting in this change. Such a shift in the position of surface isotherms would result if the cool inshore water and the warm offshore water became thoroughly mixed together. Mixing is of course a feature in any region of turbulence, but such extensive mixing is unlikely in so short a period as two days. Then

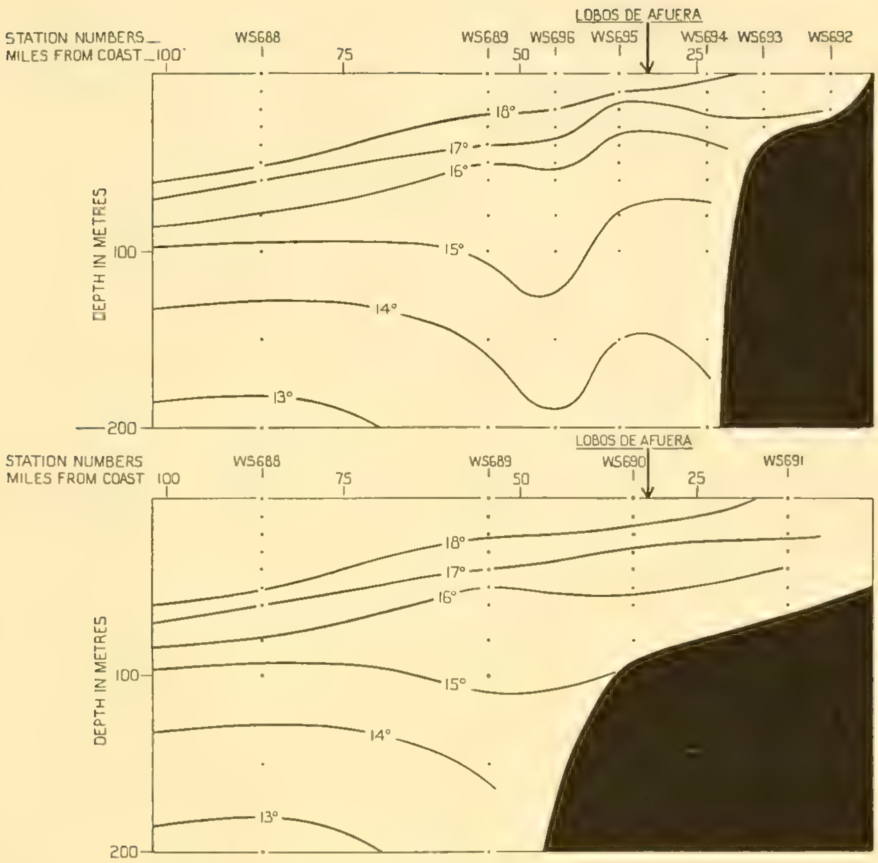

Fig. 65. Distribution of temperature off the Lobos Islands, July 17–20. Section showing the possible effect of the rocks upon upwelling. The upper section represents conditions on the sheltered, the lower on the exposed side, of the Lobos de Afuera; their relative positions are indicated by arrows. The positions of these stations are shown in Fig. 12.

Table XIX. *Phosphate values around Lobos de Afuera*

	Milligrams P_2O_5 per cubic metre								
	Seaward of rocks		Lobos de Afuera (SE of rocks)		Lobos de Afuera (NW of rocks)		Shoreward of rocks		
Station	698	699	690	691	696	695	694	693	692
Depth (m.)									
0	69	69	85	85	104	100	96	90	92
20	69	85	85	85	100	108	104	104	112
40	69	100	100	100	108	108	127	—	—
60	100	104	118	113	104	112	116	—	—
Mean values									
0–20	73		85		103		100		
40–60	93		108		108		116		

Stations to the leeward and windward of the Lobos de Afuera are compared with those lying closer inshore and farther offshore. Upwelling off the windward shore of the islands is suggested by the high phosphate at Sts. WS 696 and 695, whereas at Sts. WS 690 and 691, no farther from land, it is intermediate between inshore and offshore values.

the circular drift of the ship from St. WS 630 to 635 on her return journey and the presence of a southerly counter-current off Bahia Herradura have been regarded as evidence of a coastal eddy. Less force is probably required to draw surface water for considerable distances horizontally than to lift deep water even for a short way vertically; and it is possible that for a local reason surface water is available here to flow in together with upwelled water as compensation for the divergence. The wind was rather stronger off Antofagasta than elsewhere in the vicinity. A coastal inflow of warm water from the north might, then, have been a factor contributing to the rise of surface temperature inshore, but a factor of only limited importance. Assuming a constant velocity of 38 miles a day, a breadth of 2 miles, and a surface temperature of 15° C. (Table I and Appendix IV), its heat capacity was obviously far too small materially to affect surface temperatures over a wide area. The temperature rise from 13·93° C. on June 8 to 15·31° C. on June 10 on the position of St. WS 625 at 7 miles from shore, must evidently have been brought about by some other mechanism.

The theory advanced earlier, that the shift in surface isotherms may have indicated a subsidence of the cool water, deserves then to be considered. The change of surface temperature simultaneously with change of wind at St. WS 630 argues a dependence of water movement on wind: and the vigorous upwelling on the outward journey argues strong divergence of surface water from the coast. Dependence of the latter on wind may be inferred as a probability and indeed is to be expected from Ekman's theory. From this the southerly wind is to be looked upon as a force capable of raising water from the lower layers. And as these are heavier than the surface layers offshore, they may not unreasonably be supposed to sink when the wind fails or reverses its direction. That this was happening on the return journey may be gathered not only from the shoreward shift of surface isotherms above noted, but also from the shoreward drift of the ship during the course of St. WS 630 (Fig. 9).

In our analysis of the conditions at Antofagasta, we are hampered by having no simultaneous observations outside the immediate neighbourhood. While it cannot be known whether an eddy in the north co-existed with upwelling in the south on June 8, we do know that on June 10, simultaneously with evidence of eddy in the north, upwelling in the south had ceased: the surface temperature at St. WS 625 in the upwelling area of June 8 was 13·93° C., and after the change of wind it had risen to 15·31° C. on June 10. Thus while the ship was drifting to the northward and finding warm water off Bahia Herradura, upwelling in the former upwelling area had definitely slackened and the surface temperature had risen. This and the fact that changes in surface temperature and changes in the wind force were simultaneous, lends definite support to the view that subsidence played some part in this disappearance of the low temperatures.

Guañape Islands

The shift of surface isotherms with change of wind off the Guañape Islands forms an interesting contrast to the conditions off Antofagasta, since movement was here anticyclonic and not cyclonic. Here during the journey towards the shore (towards

Salaverry), the wind blew predominantly from the east to east-south-east and the isotherms of 20, 19, 18 and 17° C. were at 55, 46, 42 and 14·5 miles from the shore (pp. 152–3). Then the wind changed to south-west and south-south-west, and on the run seawards from the Guañape Islands on a line not far from the first, it was discovered that all isotherms had moved closer inshore: the same isotherms were found at 46, 34, 29 and 8·5 miles respectively. As at Antofagasta, divergence and convergence of the surface water with the coast—of which upwelling and changes of surface temperature are indices—appear to show some dependence on local wind. Off this coast the south-east wind is approximately parallel to the shore, and the deflection westwards of surface waters is again to be interpreted as showing the influence of the earth's rotation. The closing of surface isotherms with the coast during the south-westerly onshore wind shows that the forces leading to divergence had relaxed, and it is possible that subsidence of the heavier inshore water was in progress.

At the same time it is also possible that the cool inshore water was carried away by current towards the north (Table I), and that the warm offshore water was brought nearer to the coast through a modification of the anticyclonic swirl described on p. 192. Reference to Fig. 63 will show that a shift of surface isotherms towards the coast would follow if—and in fact might be evidence that—the southern end of the swirl and particularly the convergence of the warm wedge with the coast had travelled northwards. Movement of the kind might take place with or without simultaneous subsidence of the inshore water.

Callao

The third illustration is provided by a series of observations outside Callao, off the island of Palominos, which was visited on eight occasions between June 26 and August 20. The graph in Fig. 51 shows that the observations fall into three periods. During the first the water at all depths experienced a rise of temperature amounting at the surface to a mean daily rise of 0·04° C.; during the second period a fall of 0·082° C. per day; and during the third a rise of 0·065° C. per day. Corresponding with these changes of temperature the wind direction and force changed too. During the period of strong upwelling the wind had the greatest easterly component and blew with a mean velocity of 7 m.p.h. During the periods of weak upwelling or of subsidence the wind blew less vigorously and with a smaller easterly component. Although this, in principle, tallies with other observations, the change in hydrological conditions seems excessive when set against the wind alteration.

These changes, together with other data, have been cited on p. 194 as evidence of the possibility that on or before June 26 the warm wedge was converging with the coast southwards of Callao. Between July 8 and 11, on the other hand, temperature observations suggest convergence of the wedge northwards of Callao (*vide supra*, withdrawal of cool water from the Guañape Islands). These data, considered in relation to the observations off Palominos Island (Fig. 51), suggest that the temperature off Palominos rose with the approach of the warm wedge from the south and sank with its withdrawal to the north. Observations after these dates are too scanty to show whether the further

temperature changes off Palominos Island may be similarly related to the position of convergence of the wedge.

Swirls of the type described must continually vary in size and location in accordance with distant and local forces: and this should be borne in mind when weighing evidence of correlation between a wind which was light and the upwelling off Palominos Island, or again between a wind which is very local such as the *virazon* and the convergence of warm water with the Pisco-Callao-Guañape Islands stretch of coast.

The possible working here of a seiche is discussed on p. 212.

Other localities

Other instances of an apparently direct relation between surface temperature and wind have already been noted; of cool inshore water and south-easterly wind at Pichidanque Bay (p. 140) and San Juan (pp. 148–51), and warm inshore water with north-westerly wind off Cape Carranza (p. 135), and in the Caldera neighbourhood (p. 140). Compare also the seasonal changes noted on pp. 226–7.

At many localities, however, there was an appearance of upwelling in comparatively calm weather. The evidence at Pichidanque Bay, for example, goes to show that conditions had been calm for many weeks before our observations were made; both nutrient salts and plankton were depleted and a thermocline was becoming established at 40–50 m.: yet traces of definite upwelling were present (Fig. 21). Again upwelling off Callao and perhaps off the Guañape Islands seems heavy for the strength of local winds. At Arica there was no sign of an earlier meteorological disturbance: calm weather on this part of the coast is traditional, and out to sea a thermocline at 30–40 m. was clearly established (Fig. 31). Yet upwelling from a depth of 50 m. was conspicuous.

Evidence of a foregoing period of calm, at Arica and Pichidanque Bay at any rate, precludes the possibility of interpreting the upward curve of isotherms and isohalines as subsidence on an extensive scale. These must be examples of upwelling caused by forces at some distance from the regions under consideration. Such was indeed inferred by Dinklage in 1874 (Schott, 1891, p. 215) and by Buchan (1895). The latter writes:

It is probable that the great volume of, and distance travelled by, these currents in the broad Pacific as compared with other oceans directly results in a stronger and more widespread upwelling, accompanied with a correspondingly extensive diminution of temperature.

The formation of currents by aspiration is well known and is well illustrated off Northern Peru where the coastal water off Punta Aguja and Punta Parina is drawn west-north-west in the wake of the South Equatorial Current (Ferrel, 1860, p. 55). The strong inshore current of 48 miles a day off Arica, and, in part, the inshore current off the Guañape Islands, may be supposed to be due to the same cause, for each of these localities lay to the southward of regions of strong surface drift.

It becomes a question whether a coastal current caused by aspiration in this manner may not diverge from the coast as a result of the earth's rotation and so induce upwelling. In respect of wind-induced current, Ekman concludes:

The most striking result of the coast's influence is that *a wind is able indirectly to produce a current more or less in its own direction from the surface down to the bottom*, while in the absence of coasts the wind's effect would be limited to a comparatively thin surface layer.

Thus the presence of a coast should have a restraining effect on the influence of the earth's rotation. Our results off Antofagasta and the Guañape Islands suggested that the surface layers diverged from the coast under the influence of a wind parallel to it, both over deep and shallow water: the restraining influence of the coast on the influence of the earth's rotation must then have been partly overcome. The actual conditions in the Peru Current differ from those employed in Ekman's type problems, and to this may be due the apparent lack of agreement. If a current induced by aspiration is at all comparable with a current induced by wind, the inshore coastal current at Arica may be expected to diverge, and on this account upwelling may be accentuated.

Summarizing these conclusions, the current at the Guañape Islands and especially the strong coastal current in the absence of local wind at Arica are regarded as having been produced through aspiration of the surface layers, by wind and wind drift outside these regions. That such coastal current may induce upwelling is suggested by the analogous behaviour of wind-induced current off Antofagasta and the Guañape Islands.

The universality of upwelling off both Chile and Peru is evidence that westerly set of the surface layers in the ocean at large is widespread. That such westerly set inshore must be induced by aspiration as a result of winds and oceanic drift remote from the coastal region is inferred by reference to the conditions at Pichidanque Bay and Callao, and from the fact that winds are stronger and more easterly in the open ocean. At these localities upwelling could be due to no other cause since no surface current was observable.

That the degree of upwelling showed a considerable uniformity over the whole coast suggests that this indirect effect of distant wind may outweigh in importance the local winds having a direct action. This may indeed be a principle operating along the length of the west coast, and so to speak guarantees a minimal quantity of cool water close inshore even under the most diverse local conditions. Upwelling would be greatly augmented by local southerly wind and northerly current, but perhaps never altogether suppressed by local contrary wind and counter-current. Thus the effect of swirls and eddies would merely be to retard organic production in one place and to accelerate it in another.

EFFECT OF LATITUDE

Wind and current are stronger and more regular on the coasts of Peru than on the coasts of Chile. There is, moreover, a greater difference between the densities of the water at the surface and the water at the upwelling depth off Chile than there is off Peru;[1] so that off Chile more force is presumably required to cause upwelling. Yet upwelling is not so very much more vigorous off Peru, and it certainly does not seem commensurate with the stronger wind, the current and more uniform density; and there are probably other factors whose influence have yet to be considered. One of these may be the greater area of shallow water and greater area of the current included in the upper depth of frictional influence in Peruvian than in Chilean waters (see p. 204). Another factor may be the effect produced on a current by the earth's rotation in

[1] Density, together with other physical and chemical data, will be published in due course in the *Discovery Reports*.

different latitudes. It is well known that the deflecting force is a function of latitude, is maximal at the poles and is zero at the equator. It may be a factor of considerable importance contributing to the uniformity of hydrological conditions on the west coast.

EFFECT OF SEICHE

The effect of seiches in oceanic hydrology has been noted in the Bay of Bengal by Sewell (1928) and in the North Atlantic by Helland-Hansen and Nansen (1926). The possibility that the oscillation in the temperature of the upper layers of the sea at Callao from June 26 to August 20, might be ascribed to a temperature seiche should be considered.[1] The data illustrated in Fig. 51 indicate that off Callao a peak maximum temperature and a peak minimum temperature occurred on July 4–8 and August 4–8. These peaks may represent respectively the trough and the crest of a subsurface oceanic wave of cool water at the coast.

According to these dates, the seiche would have a period of about two months. Wedderburn (1911) calculates that under certain stated conditions, a temperature seiche in the Atlantic might have a period of 34 days. Hypothetical as this conclusion must be, it does not seem inconsistent with the possibility admitted by our data that in the Pacific a seiche might have a period of double this length. The period of a seiche in so small a basin as the Bay of Bengal was observed to lie between 17 and 19 days (Sewell, p. 168), whereas the North Atlantic seiche showed indications of being diurnal (Harvey, 1928). Thus the possibilities are wide.

Unfortunately observations have not been made during other maxima and minima before and after these dates, and they are therefore insufficient to show periodicity which is an essential feature of the seiche. Such a seiche, if it existed in the South Pacific, would have a decided influence upon upwelling; on the crest, subsurface water would be closer to the surface and relatively weak forces would be able to bring cool water and abundant nutrient salts to the surface, whereas on the trough, wind and current of considerable magnitude would have comparatively little effect on this water. On pp. 208–9 the rise in temperature off the Guañape Islands on July 10 and 11 has been attributed to change of wind: seiche is probably not operating here, because Fig. 51 shows that during this date, if a seiche were working, the temperature would be falling. Until some knowledge has been obtained on seiche action in the Pacific, the full effects on upwelling of the separate factors outlined in the foregoing pages cannot properly be understood.

SPEED OF UPWELLING

No calculations have been made to indicate the rate at which water may well up, but the apparent quick response of the temperature at and below the surface to changes of wind supports Schott's view that a speed of 15 m. a month as suggested by McEwen (1929, p. 259) is far too slow. Rate of change in hydrological conditions is also considered on p. 213.

[1] I am indebted to Lt.-Col. R. B. Seymour Sewell for this suggestion.

THE EVIDENCE FOR THE THEORY OF SUBSIDENCE[1]

It will be convenient to summarize the evidence scattered among the earlier sections and discussed above in support of and against a theory that an onset of contrary conditions may be followed by some subsidence of the upwelled water.

According to Coker (1918), fishermen have long believed in a swinging out to sea of the current to explain the disappearance of cool water from the coast; and its occasional disappearance is noted in sailing directions. In earlier pages (pp. 206–9), such disappearance of the cool water has been supposed possible, not by a horizontal swing but by a vertical swing within the current.

At Antofagasta and the Guañape Islands, the rise in temperature was rapid but so also, generally speaking, were the horizontal currents which might therefore have been the cause; at Antofagasta by a cyclonic inflow of warm water from the north, and at the Guañape Islands by an anticyclonic outflow of cold water to the north-west.

At Antofagasta, (1) the drift of the ship against the wind and towards the shore at St. WS 630, and (2) the rise in temperature simultaneously with a falling off of the wind strength well before the subsequent change in its direction (Sts. WS 629–630), are together facts strongly in support of the subsidence theory (see p. 142). For the rise in temperature between Sts. WS 629 and 630 might alone have meant nothing more than the admixture of upwelled with oceanic water. The magnitude of the shorewards drift at St. WS 630 at 17–26 miles from land could not easily be attributed to the coastal eddy by which the inrush of warm water off Bahia Herradura may be explained (Figs. 9 and 28). The fact that the second line of observations lay in the region of eddy and not over the first line weakens the value of any evidence that might be furnished by comparison of subsurface isotherms on these two lines. At the present stage the evidence may be considered insufficient to decide how much of the rise in temperature on the second line was due to subsidence and how much due to admixture with oceanic water and the eddy. It is certainly suggestive that the three mechanisms were in operation.

At the Guañape Islands the continuance of northerly current after change of the wind may have been caused by aspiration from the north: and the conditions bore some resemblance to those at Arica, where the seemingly paradoxical co-existence of convergence and divergence has been noted. The evidence is clearly insufficient to decide the question whether some subsidence had occurred as a result of the wind change.

Three alternatives have been suggested as the possible causes of the temperature oscillation at Callao: the action of local wind; a shift in the position of the anticyclonic swirls, with especial reference to the point of convergence of the wedge; and the action of seiche. The first was considered insufficient, alone, to cause the temperature changes, while of the other two the data are inconclusive. While any horizontal current off Callao must have been very slow (p. 129), the temperature changes also were very slow

[1] The term "subsidence" here denotes a reversion of the water layers towards a condition of horizontal stratification and should be distinguished from sinking brought about through accession of density.

(see Table VII, p. 170). Subsidence between the dates June 25 and July 8 and August 7–20 remains a probability but cannot be regarded proven.

SINKING OF NEWLY MIXED WATER

Indications of this phenomenon off Caldera (p. 140) leads one to suppose that the mixing of upwelled with oceanic water must lead frequently to the formation of heavier water which thereupon sinks on the outer edge of the zone of uprising. Such sinking of the product of recent mixing is, of course, to be distinguished from subsidence of recently upwelled water. Upwelling and subsidence of the lower layers may be described as a see-saw motion dependent upon variations of wind or of other forces responsible for the divergence of surface water from the coast: subsidence restores equilibrium by the passive method of letting the water layers revert towards a condition of horizontal stratification. Sinking of heavier water, on the other hand, restores equilibrium by disrupting thermal stratification; it is irreversible in its action. Although newly mixed water which is sinking is independent of any external force other than gravity, it may be to a large extent dependent on wind action for its inception. Thus at Caldera its appearance coincided with the convergence of warm offshore water with the cool inshore water, and with local northerly wind. Whether the cool water inshore was welling up concurrently with this convergence of the warm water, as a result of the southerly winds recorded offshore or of winds even farther from the coast, or whether the cool inshore water was subsiding, is not known.

Other instances of sinking of newly mixed water are probably to be found among our sections; though most to be expected in the neighbourhood of the subtropical convergence, it is probably a phenomenon of importance in the mixing process of the coastal current waters. At Cape Carranza, an appearance of sinking water at St. WS 597 is also correlated with northerly wind, but cannot illustrate this phenomenon since, south of the subtropical convergence, the water is less saline offshore than inshore.

CENTRES OF UPWELLING AND OTHER IRREGULARITIES OF THE CURRENT

CENTRES OF UPWELLING

Schott has suggested that the length of coast between Coquimbo and Punta Parina may be divided into four regions,[1] each distinguished by strong upwelling which sets in with a sudden lowering of temperature and then dies away northwards so that finally almost normal temperatures are found over short distances. In Schott's graph comparing inshore temperatures with those at 80–100 miles offshore, the points of conspicuous upwelling are Antofagasta, San Juan and Punta Aguja. The points of least upwelling are north of Coquimbo, south of Antofagasta, Arica and Puerto Chicama.

[1] I have used the word "region" instead of Schott's word "zone" because I have already used the word zone in a different sense elsewhere.

The variations from this order in September 1927 and November 1929 are slight, amounting principally to a state of vigorous upwelling off Puerto Chicama in 1929.

Our experience was much the same; we found very much more active upwelling off some parts of the coast than off others, and the regions noted by Schott can be distinguished both in the curves in Fig. 66 and in the chart of surface temperatures in Figs. 16 and 17. Thus in region I from lat. 30 to 25° S, vigorous upwelling off Caldera lowers the mean temperatures in lat. 27–28° S as far as 10 miles offshore. The second focus of upwelling occurs off Antofagasta in region II in lat. 25–18° S. In region III (lat. 18–8° S) the upwelling is at San Juan, but in region IV upwelling off the Lobos Islands was not quite so vigorous. Points of exceptional warmth were found south of Antofagasta in region I (Fig. 9) and in moderation off Callao in region III, but at no other localities close inshore. This agreement in the localities of major upwelling makes it very likely that these centres of upwelling are more or less permanent. As a natural consequence follow differences in the breadth of the cool zone and in the gradient between inshore and offshore temperatures (see Figs. 29 and 30).

Particular interest attaches to these centres since they are found to correspond with the anticyclonic swirls suggested on p. 192 and Fig. 63. The two swirls off Peru are illustrated diagrammatically in Fig. 66 by arrows which curve away from the graphs in the divergence regions of strong upwelling, but curve towards them in the warm convergence regions. The very similar nature of the upwelling centres off Chile and their comparative permanency makes the existence of similar swirls, though weaker and probably less pronounced, to be expected off the Chilean coast. The probable positions of the hypothetical swirls are also marked in the figure.

IRREGULARITIES OF THE CURRENT

No account of the current would be complete without some reference to its extraordinary variability. In almost every particular, drift, temperature, breadth, colour, etc., it is fraught with irregularity. In their persistent references to the uniformity of the conditions on the west coast, earlier workers are apt to mislead. Thus Murphy (1925) says: "Extraordinary uniformity is, after all, the outstanding oceanic feature of the Peruvian littoral." And Schott (1931) writes: "On the large scale the temperature too is uniform, for in the water it varies little with the latitude and according to no obvious law, and little with the season." He is accounting for the slight differences between mean temperatures in low and high latitudes within the coastal region and the equable climate that results: yet later (1932) he writes: "...therefore the quantity of upwelling water also varies from place to place. In consequence of this situation the surface temperature...are depressed in complicated and irregular variations along the coast." These variations are a conspicuous feature of the current and may be due very largely to the swirls above described; we may illustrate their nature with a few selected examples.

Changes of temperature along the coast sometimes occur abruptly within short distances, and the following record as the ship left Coquimbo Harbour on a course of 353°

may be cited. It is suggested on p. 140 that this may have been the result of a recent change of wind.

Table XX. *Fluctuation of surface temperature on* 3. *vi.* 31, *on a course of* 353° *from Coquimbo Harbour to* 28° 47′ *S*, 71° 44′ *W*

Hour	Distance from shore miles (approx.)	Surface temperature ° C.
1415	2	15·10
1500	2–3	14·64
1530	5	14·42
1600	9	13·55
1630	12	14·58
1700	14	14·45
1800	14	13·95
2000	10	15·03
5000	16	15·20

Temperatures are found to vary from one year to another in a way apparently unrelated to seasonal changes. The anomaly between our records and those of Schott at Arica have been noted on p. 203. In Pisco Harbour the water inshore is sometimes warmer than offshore, sometimes cooler. In September 1927 and November 1929 the 'Emden' and 'Nitocris' registered respectively less than 15 and 16° C., and the water offshore was presumably warmer. But Murphy in 1919 and we ourselves in 1931 found the reverse. He found 20·00° and 20·56° C. in October and November, and we found 19·10° C. in June, whereas southwards of Paracas Peninsula readings were as low as 14·89° C. We have unfortunately no salinity observations with which to confirm Murphy's suggestion that high temperatures here may be explained by the discharge of freshet waters from the Pisco River. If the swirls altered their position as suggested on p. 210 these changes would be readily explained.

Changes in the distribution of surface isotherms from day to day, almost from hour to hour, will have been noted in the paragraphs dealing with the effect of wind upon upwelling. To these examples may be added a record of the temperatures in the convergence region off Capo Blanco before and after the ship's sojourn of five days in Talara. The changes in the probable distribution of isotherms are illustrated in Figs. 70 and 71. Such changes as these have been noted by many earlier observers and may be regarded as a normal feature of this coast.

Lavalle (1924) has described an invasion of the coastal waters of Peru by a counter-current which occurs annually between the months of April and July, and which he supposes to originate from the Equatorial Counter-current. Its strength varies with the year, but its convergence with the cool coastal water produces *aguaje*, and in 1923 drove away the guano birds.

Lavalle publishes records of surface temperature off the Guañape Islands and Palominos Island for the months of April, May and June during the years 1921–3. From

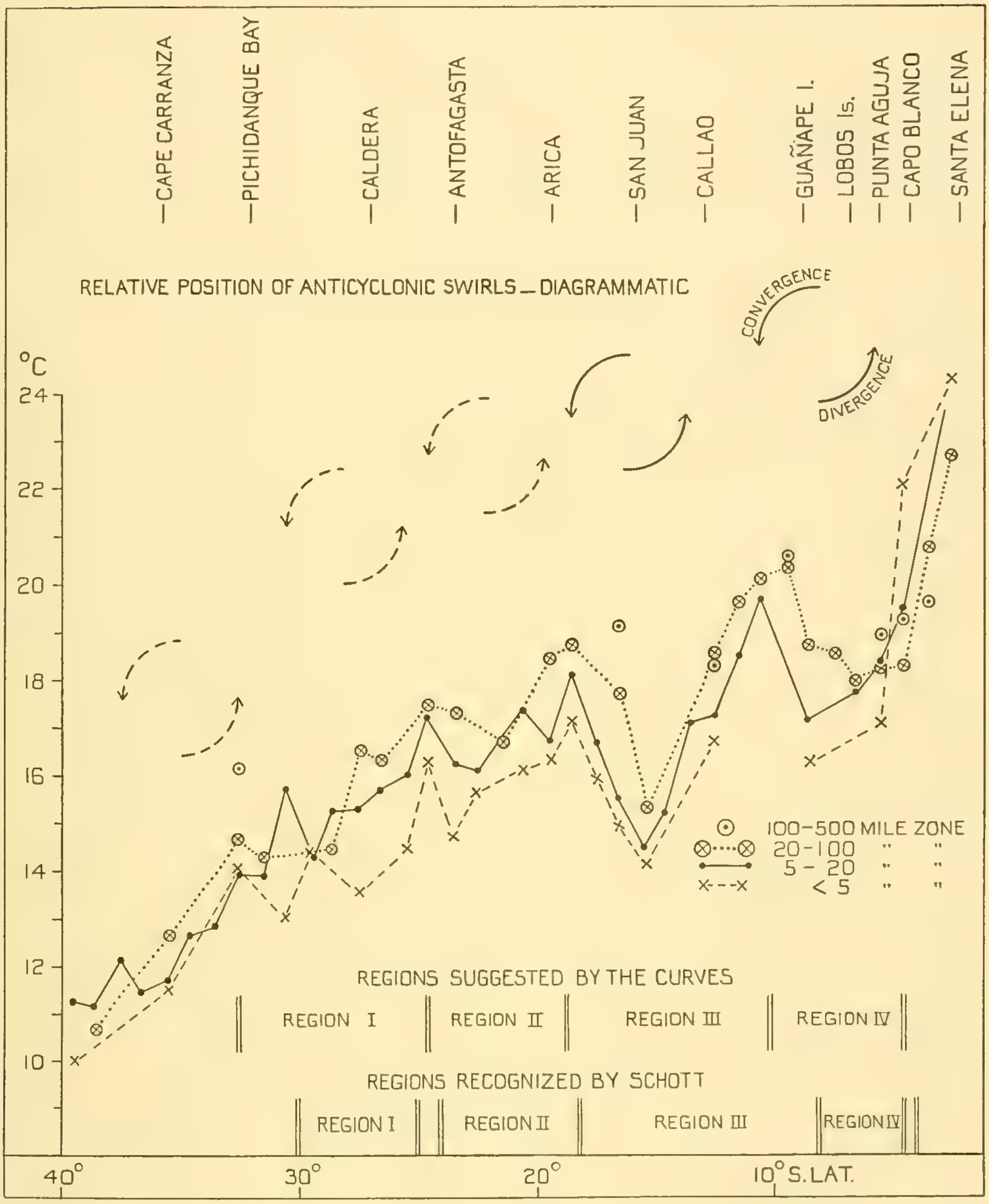

Fig. 66. Centres of upwelling. The three curves illustrate the mean surface temperature of the current along its path; they represent three zones parallel to the coast at <5 miles, 5–20 miles and 20–100 miles from it. Above the curves, the two anticyclonic swirls off Peru are shown diagrammatically, their points of convergence and divergence corresponding to the peaks and the dips in the curves. Equivalent swirls are postulated off the Chilean coast. Below the curves, the four centres of upwelling are identified with the regions recognized by Schott. The curves represent a combination of the data given in Appendix VI and Fig. 34. Temperature records at greater distances than 100 miles are given as ringed dots.

these data[1] the remarkable fact emerges that off the more southern Palominos Island the April and May temperatures were, on the whole, higher than those off the Guañape Islands lying some 240 miles to the northward. Such a distribution of temperature would not arise from a counter-current of warm water flowing from north to south *along the coast*, and it is unlikely, therefore, to be due to a repetition of the *Niño* current out of season. Lavalle gives no salinity data by which the origin of this water can be established, but the temperature data might be explained if the counter-current came from the open ocean and was an over-developed wedge of the type met with during our survey.

PHOSPHATE AND ORGANIC PRODUCTION

In an earlier section, an attempt has been made to correlate organic production on the west coast with the hydrological conditions. A study of the phosphate content has shown that the concentration of nutrient salts at the surface varies according to the extent of the cool water in the different localities (pp. 182–3); and that the rich nutrient salts may be identified with upwelling water is shown by comparing Figs. 54–61 with Figs. 18–50, the corresponding sections of temperature and salinity.

The relation of nutrient salts to the plant life in the sea is best known from the work of European investigators, and in the sub-Antarctic from results recently obtained by the Discovery investigations (Hardy and Gunther, 1935). An examination of this relationship in the Peru Coastal Current has shed interesting light not only on the conditions met with at the time of the survey but possibly also for some considerable time in the immediate past.

Volumetric measurement of settled phytoplankton shows that within 100 miles of the land, catches are on average larger than beyond (Table XI); that in regions of rich phosphate the average catch is larger than in regions of poor phosphate (Table XIII); and that this close relation between the two is suggestive, on the strength of results of Atkins and others, of a dependence of plankton upon phosphate.[2]

This dependence of the phytoplankton upon inorganic salts can be examined more closely, only if it is possible to measure their reduction with the growth of the plankton. Neither the methods employed by Atkins (1923), Gran (1927) or Schreiber (1927) are available to a ship on the move, and an alternative though less accurate method has been considered. It consists in comparing the phosphate concentrations above and below the compensation point at each station, and it assumes that initially the phosphate concentrations at the surface and at 100 m. are approximately the same or within limits bear the same relation to each other, and that subsequent changes are comparatively

[1] The higher index of the maximum and minimum thermometer appears to have been misread at both islands, but the error does not seem to affect the comparative value of the data.

[2] In Table XIII we see incidentally that when the zooplankton exceeds a certain concentration the phytoplankton is severely reduced. That the phytoplankton has been cropped down by the zooplankton which is here in greater quantity than at any of the other localities listed, is put forward as the most likely of possible explanations.

small in the lower layer. The mean values of the phosphate concentrations at 0 and 20 m. on the one hand and 80 and 100 m. on the other have been chosen as representative of these two levels. The method appears to be applicable to an area such as this in which the surface waters close inshore are replenished by upwelling of nutrient salts in a zone where vertical mixing is extensive within 100 m. of the surface, and in which these waters drift away from the coast and acquire thermal stratification as they enter upon oceanic conditions. It is not applicable, however, to counter-currents introduced into the upwelling area from the open ocean.

Phosphate data have been studied by this method at three localities, at Cape Carranza, Antofagasta and San Juan, but elsewhere the catches of phytoplankton were small and our preliminary measurements unrepresentative. In Tables XIV and XV the percentage figures expressing depletion for stations of different phytoplankton concentration have been averaged. The curve in Fig. 62 shows that depletion increases with the phytoplankton concentration, and the fact that five points out of seven lie on a straight line suggests a direct relation between the two. The relatively big depletion (21 per cent) of phosphate corresponding to the thirteen stations where the volume of phytoplankton averaged less than 25 c.c., would be explained if phytoplankton at these stations had been grazed heavily by herbivorous zooplankton; it is not wished, however, to stress the accuracy of this curve whose straightforwardness was unexpected.

Conditions on the west coast are thus seen to fall into a series, grading from localities of minimal cool water, nutrient salts and plankton, to localities of active upwelling, rich nutrient salts and rich plankton. At Pichidanque Bay, Arica and Callao in July the weather had been calm for a considerable time and the surface layers were relatively impoverished of phytoplankton; at the first phosphate was negligible, at the others it was not estimated. At Caldera such a period of calm had recently been broken by southerly winds and upwelling, with the result that phosphate at the surface had reached medium values but phytoplankton had not had time to develop far. At Antofagasta where upwelling seemed to have been in progress for longer, the largest catches were taken at 7–15 miles from the coast, and the most recently upwelled water lying inshore had a small diatom content. At Cape Carranza, San Juan and the lines off northern Peru, wherever phosphate was examined it was rich, and heavy catches of plankton were taken at all of them. Considering the movement in the current the accommodation of the plankton to the hydrological conditions is remarkable.

The uniformity claimed for this area by many writers might lead to the supposition that it is uniformly fertile over its entire length. The differences in the abundance of phytoplankton, noted above in the separate localities, would be attributable to temporary changes in hydrological conditions. In support of this view is the fact that upwelling was marked in all the localities and that they are therefore all productive. The majority of evidence is, however, against this view. The apparent permanency of the centres of major upwelling, together with the other facts from which the existence of large anticyclonic swirls has been inferred, and lastly the adjustment of the phytoplankton to the recognized upwelling centres, go to show that certain localities are

perennially more fertile than others. In this event, the poverty of phytoplankton at such localities as Callao, Arica and Pichidanque Bay may be interpreted, not only as an indication of conditions in the immediate past, but also perhaps as evidence of the inflow of barren oceanic water in regions of convergence.

If vertical currents are important as a source of production, horizontal currents may be no less important in collecting plankton together in patches and thus in providing the larger animals with a feeding ground. With reference to the vertical migration of plankton animals, Hardy (1935) has shown the possibilities in navigation open to an organism migrating regularly between two currents. By this mechanism he has shown how animals might be collected together in patches, disperse and perhaps migrate towards food or away from an uncongenial environment.

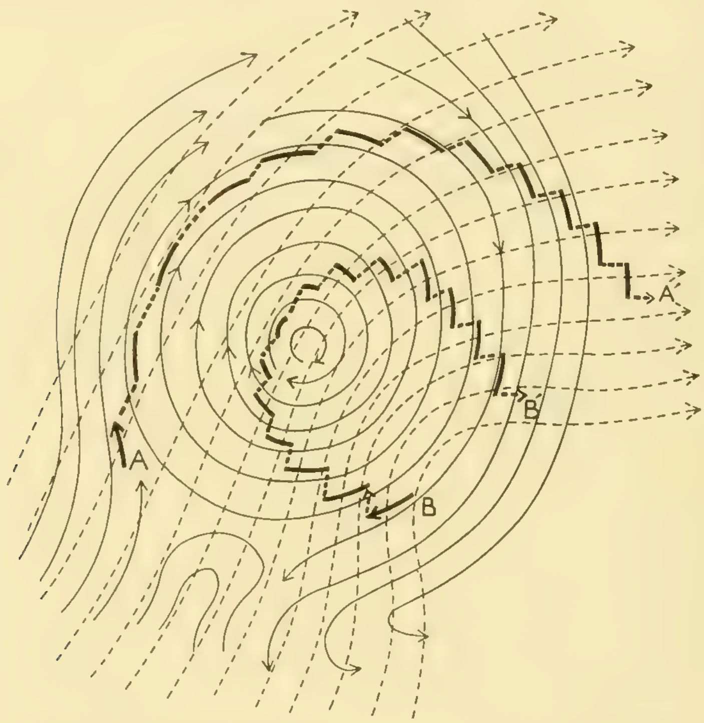

Fig. 67. Hypothetical diagram of a surface eddy. (After Hardy.)

In this connection the collection of animals in the eddy off the Lobos Islands becomes of great interest. Hardy gives two hypothetical cases of currents which would collect organisms together without their having to alter their migrational rhythm. The first is of an eddy situated over another current. We are indebted to him for permission to reproduce his illustration in Fig. 67; the lower current is represented by fine broken lines and the paths of two hypothetically migrating organisms A and B which are carried to the positions A' and B' are shown by heavy lines. Inside the Lobos Islands, a surface layer of warm saline water is strongly suggestive of an eddy lying above the main current: and here the collection of thick zooplankton, of anchovy, bonito, birds, seals and whales, is probably to be identified in principle with the theoretical considerations Hardy has sketched.

Although a similar effect might not be expected in the larger anticyclonic swirls, the high temperature of the warm wedge checking perhaps the range of vertical migration, yet an eddy of this type seems to have interesting consequences on the plankton (see pp. 229–33). Attention might also be drawn to the identical observations made by Ulloa (Juan and Ulloa, 1748) and Smith (1899), of a patch of green water off the Island of Santa Maria in southern Chile, but in the absence of further data, this is a coincidence which must remain a matter of record.

COLOUR OF THE CURRENT

The various colours of the water described on pp. 173–5 and illustrated in Plate XVI, at first seeming to lack orderly arrangement may be grouped into three classes:

1. The three basal colour types, to one or other of which all oceanic water may be referred. As shown by Buchanan these are either blue, indigo or green. They have transparency.

2. Opaque colours occurring near land and at other centres of exceptional phytoplankton production such as in the polar regions. They are presumably referable to animal or terrigenous origins; they are usually reddish, muddy or chalky, and often occur in patches of a few hundred yards or a few miles in extent. Intermediate browns, ochres, khaki, etc., might be produced either as the result of abnormal conditions (see below) or by admixture of 1 and 2.

3. Colours of holophytic organisms such as *Trichodesmium*, colonial Radiolaria and flagellates. They are straw-coloured, orange or red, and they, apparently, may occur at any distance from land: these also occur in swarms.

The normal colour distribution in the eastern South Pacific may be said to consist of a coastal zone of green modified locally by varying concentrations of the colours of classes 2 and 3, and this is flanked in the open ocean by indigo in the temperate and ultramarine in the tropical regions. Indigo and blue being basal colour types in these latitudes, are not understood as being colours peculiar to the Peru Coastal Current.

While the green colour of the current is evidently attributable to phytoplankton, and while aberrant colours when due to the swarming of holophytic organisms can usually be identified by the predominance of a particular species, so far our knowledge of the nature of the colours of class 2 comes mainly from indirect evidence.

Near Callao, for example, no specific organism seemed to be associated particularly with the rusty coloured patch; and zooplankton was no more abundant here, at the Guañape Islands, or at Pisco, where the more unusual discolorations were met with (Plate XVI, figs. 6, 7 and 11), than at other localities where the water was green. Moreover, the great majority of zooplanktonic organisms not only in temperate, but in polar regions, are known to make diurnal migrations, seeking the less illumined layers during the hours of daylight (Russell, 1927, 1928, 1931; Hardy and Gunther, 1935). It is improbable therefore that in normal conditions the colour of the sea surface is much affected by the animal constituents of the plankton. The brick red swarm of euphausian

cyrtopias was the only example met with, and the parallel to the peculiar behaviour of *Euphausia superba* in the Antarctic has already been referred to. It may be noted that where there is evidence of swarming animals in earlier records, the colour is usually described as reddish (Funnel, 1729; Fitz-Roy, 1839; Rayner, 1935). The unusual discolorations have some resemblance to the colours that have been described as characteristic of *aguaje* (Raimondi, 1892; Stiglich, 1925). Further reasons for associating them with this phenomenon are given on pp. 229–33, where it is shown to be abnormal.

A point of interest is that the green colour and the colours of class 2, if produced by plankton, are practically confined to within 30 miles of the coast; whereas the zooplankton seems to be no less abundant at distances of 100 and 200 miles and the phytoplankton reaches its greatest mean volume at 80 miles offshore. It does not seem as though the areas of most intensive organic production can be identified with the coloured water, although the latter coincides with the coolest temperature and the richest phosphate. In searching for another explanation, it should be remembered that the cool inshore temperatures result in a cloud formation which hangs over the littoral as a narrow canopy over most of its length. It seems probable that conditions beneath this cloud are such that the phytoplankton finds its optimum illumination at the very surface close inshore, whereas in the open ocean where the light is more intense, diatoms may sink and scatter at lower levels and the green colour thereby lost. Dr T. J. Hart, with whom I have discussed these questions, has suggested that systrophe on the part of diatoms in the well-illuminated zone might lead to a similar contrast between the blue colour of this water and the green in the zone where cloud allows full expansion of the chromatophores (Marshall and Orr, 1928). The zooplankton, though reacting differently to light, might occupy a higher level in the coastal zone, and in this way fish would also come closer to the surface inshore than offshore, and this might account for the restriction of the birds and seals to the very narrowest zone. This would be brought about equally if the fish favoured littoral rather than oceanic species of the plankton.[1]

BOUNDARIES OF THE PERU COASTAL CURRENT

Though sharing in the general anticyclonic circulation, the coastal region and the open ocean of the eastern South Pacific have been seen to show profound hydrological differences. In the open ocean the South-East Trade is normally developed, whereas on the Chilean coast the wind weakens and has a meridianal direction. In the open ocean the northerly surface drift has a large westerly component, whereas close inshore the drift is parallel to the coast. These currents, acting in conjunction with the earth's rotation, produce a divergence of surface water from the coast whereby the lower layers are induced to well up in compensation. Contrasted with these inshore vertical

[1] Any modification of coastal colour that might be due to the distribution of zooplankton would be explained if the littoral species were more opaque than the oceanic. It is well known how well adapted to their environment are the pelagic organisms of tropical seas, being either transparent or blue or having silvery scales capable of almost perfect reflection.

currents the surface layers of the open ocean are cut off sharply from those below by a well-defined discontinuity layer which checks vertical mixing. Above the discontinuity layer a depletion of nutrient salts brought about by the phytoplankton is followed further west by a decrease of the latter and of the zooplankton: in this environment, species are oceanic. Near the coast, on the other hand, where upwelling provides a constant supply of nutrient salts at the surface, a dense growth of phytoplankton is possible, and this leads to a wealthy plankton fauna and to immense numbers of animals of economic importance. The species here are littoral. Temperature and salinity of the surface inshore and offshore are to some extent symptomatic of these changes.

Beneath the surface, a northerly current of sub-Antarctic origin, and a southerly warm highly saline return current wedged between sub-Antarctic water and the Antarctic intermediate water, appear to be features characteristic of the coastal water. They appear to be drawn towards the upwelling region in compensation for the upwelling water and thus may not feature in the open ocean.

Thus in the upper 400 m., biological, chemical, and physical characteristics, both of the surface and of the deeper layers, distinguish the inshore from the offshore waters. Meteorological differences also exist, and among them the condensation of cloud over the cool upwelling zone should be mentioned. As a result of this lessened illumination, phytoplankton probably comes close to the surface inshore, but in the open ocean either affects systrophe or sinks deeper, with the consequence that inshore waters are normally coloured green, whereas waters of the open ocean are ultramarine.

In view of the desirability of keeping the distinct identity of the two regions in mind, the oceanic drift will be distinguished from the coastal current by the name Peru Oceanic Current. The Peru Coastal Current will be kept for the system of inshore currents with which the name Humboldt Current has often been associated. The name Peru Oceanic Current will be kept exclusively for the waters offshore, different in composition but sharing, to some extent, the northerly movement of the anticyclonic circulation.

Salinity in the upwelling region is lower than values offshore north of the subtropical convergence, but higher inshore than offshore south of the convergence (pp. 159–62). On account of this reversal north and south, and because salinity at the surface is liable to be altered by precipitation and evaporation, temperature is perhaps a better guide to the boundary of the Coastal Current.

WESTERN BOUNDARY

The effect of upwelling upon the surface isotherms is shown in Figs. 16–17 and 29–30, where it is seen that the water inshore is some 2–5° cooler than the outermost of the observations on the same parallel, with the consequence that isotherms run in the same direction as the coast but converge with it slightly towards the lower latitudes.

The normal oceanic trend of isotherms in an east and west direction, reflecting the increase of surface temperature with decrease of latitude which occurs over the major

part of the ocean, is here subordinated to the overwhelming effect of local cooling. It is to be noted that this trend of the isotherms parallel to the coast holds over the entire region surveyed by the 'William Scoresby'. This means that the controlling influence of the upwelled water covers an area extending into the ocean at least as far as 50–130 miles off Chile and 150–250 miles off Peru (Figs. 16 and 17). The length of any line was terminated when the isotherms beneath the surface showed an almost horizontal tendency. This was necessary on grounds of economy, but it cannot be regarded as the limit of influence of the upwelling water, because our figure shows that surface isotherms still run parallel to the coast. Moreover, the presence of a series of anti-cyclonic eddies offshore, shows that coastal disturbances extend much farther. The limit of influence is evidently outside the area investigated by the 'William Scoresby'.

Schott and Schu's diagrams illustrating the mean annual disposition of surface isotherms in the Pacific lends support to this conception (Fig. 68). The isotherms run east and west over the majority of the ocean, but on approach to the South American continent they curve northwards until they run in a direction similar to those in Figs. 16 and 17. The isotherms show the effect of the coastal influence at very much greater distances off Peru than off Chile. Thus off southern Chile the isotherm of 13° C. shows distinct northerly displacement in 40° S at a distance of about 300 miles off land (say in 80° W); whereas off Peru the isotherm of 26° C. becomes displaced in 15° S at a distance of 3600–4000 miles off the coast, that is in mid-Pacific. Thus there is a gigantic wedge-shaped area of ocean with its apex in the south and its base almost over the Equator, and the temperatures over the whole of this area have the appearance of being depressed by upwelled water off the coast, Fig. 68. In this cooling below the mean temperature of waters in the eastern South Pacific it must not be overlooked, as pointed out by Sverdrup (1931), that water is being carried northwards from cooler latitudes (see pp. 195–6).

Although the influence of upwelled water may be carried westwards for great distances, and in the path of the South Equatorial Current indefinitely, the area which with advantage can be looked upon as the Peru Coastal Current proper must be very much smaller.

Owing to the variability of the Peru Coastal Current, no exact boundary can be placed between it and the Peru Oceanic Current. Not only are the zones occupied by marked northerly current, upwelling, rich nutrient salts, guano birds, coloured water, rich phytoplankton, rich zooplankton, cool water, etc., all of different breadths, but they are ever variable. Thus the temperature charts published by the Deutsche Seewarte show considerable variations in the position of isotherms from one season to another. Moreover, as a result of its deflection the water drifts across the westward boundary from the Coastal Current to the Oceanic Current.

The agreed actual position of the western boundary will therefore be arbitrary. If temperature is accepted as the criterion, one might be guided by the trend of the mean annual isotherms. It is where they change direction and run north-east and south-west that the western boundary of the Coastal Current might be placed. Using the chart

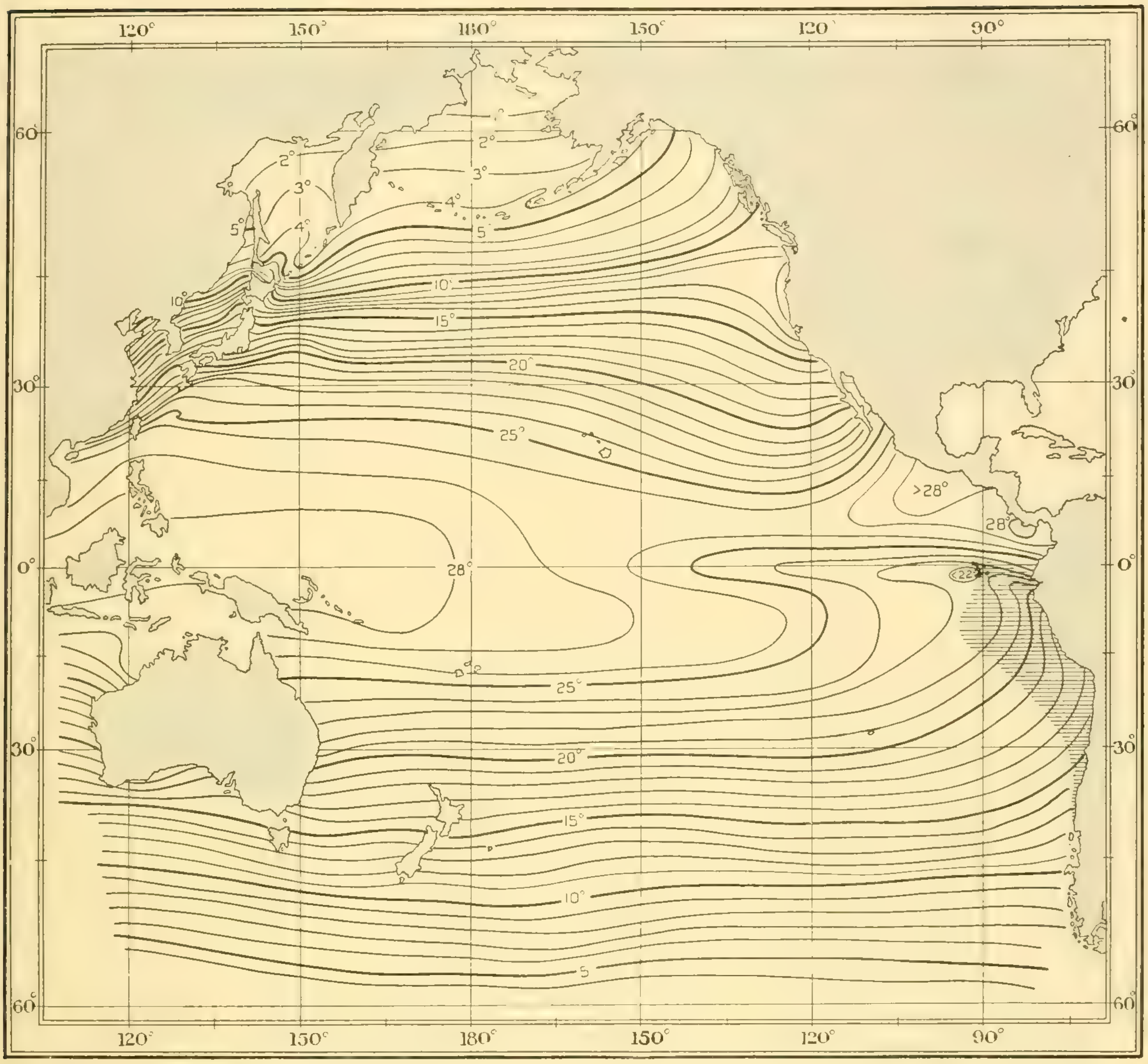

Fig. 68. The limits of the Peru Coastal Current based on the distribution of mean annual isotherms as given by Schott and Schu.

prepared by Schott and Schu (1910), the boundary might be placed in the following localities.

Table XXI. *Supposed western boundary of the Peru Coastal Current*

Latitude ° S	Longitude ° W	Miles from the coast
0	Peru Coastal Current extends westwards as South Equatorial Current	
10	95–115	1000
20	85– 90	900
30	75	180
40	South American coast	0

SOUTHERN BOUNDARY

Authors of text-books usually look to the West Wind Drift for the origin of the Peru Current (Hoffmann, 1884; Somerville, 1923). The West Wind Drift is described as dividing into two branches at its point of impingement (usually given as 40° S) against the South American continent: the Cape Horn Current flowing to the south, the Peru or Humboldt Current to the north.

It is probably true that the greater part of the sub-Antarctic water which turns northward is derived from the West Wind Drift. Such water may be considered as belonging to the Peru Current in the wider sense, and particularly to the Peru Oceanic Current. It remains oceanic until it has mixed with upwelled water. For the southern boundary of the Peru Coastal Current therefore, we should look for the most southern upwelling centre. The southernmost limit has been variously set by different writers at Cobija (Vallaux, 1930), Copiapo (Deutsche Seewarte), the region between Antofagasta and Coquimbo (Schott) and Valparaiso (Hoffmann, 1884). Schott records that upwelling began somewhat north of Coquimbo in about 29° S in September 1927. He points out that this satisfies the theory of a correspondence between depression of the temperature of the coastal waters and a low rainfall on the adjacent land. Incidentally it is close to where the subtropical convergence approaches the coast: i.e. where upwelled water becomes less saline than the open ocean. Coquimbo has a rainfall of about 100 mm. whereas Taltal in lat. 25·5° has about 15 mm. and comes definitely within the upwelling region. While Schott makes this point in his account of the Peru Current, it is to be noted that according to the chart published by Schott and Schu (1910) surface isotherms of the Pacific curve northwards near the coast in lat. 40° S. Since any northerly drift of the surface water is likely to entail some upwelling the temperature at the commencement of the Peru Coastal Current is liable to be lower than at the commencement of the Cape Horn Current, as was observed by Perez-Rosales (1857).[1]

Our own observations show that upwelling may occur at least as far south as Cape Carranza and with strength off Copiapo. Upwelling is no doubt liable to occur at any point off the coast where northerly drift happens. Mossman (1909) has shown with some precision that the dividing line between the meteorological cyclonic and anticyclonic circulations normally lies at about 41° S. South of this the prevailing wind is west-north-west in all seasons, whereas northwards the prevailing wind alternates with season. From October to March it is southerly; from April to September northerly; it brings the monsoon to the Chilean littoral, and may be felt as far north as Caldera. Hoffmann (1884) states that between Valparaiso and the 40th parallel, a northerly gale in winter is always followed by a strong southward current. Gunckel (1928) states that

[1] According to Murphy (1923) "the current laves the western coast of South America from a point somewhere south of 40° S". But he also says: "It is in accord with the abyssal topography that the current as characterized by upwelling waters, should begin near Valparaiso, for just south of that port the great bank on which Juan Fernandez lies extends to the westward more than twenty degrees of longitude." We have shown on p. 205 that the Juan Fernandez Rise has no appreciable connection with the surface waters.

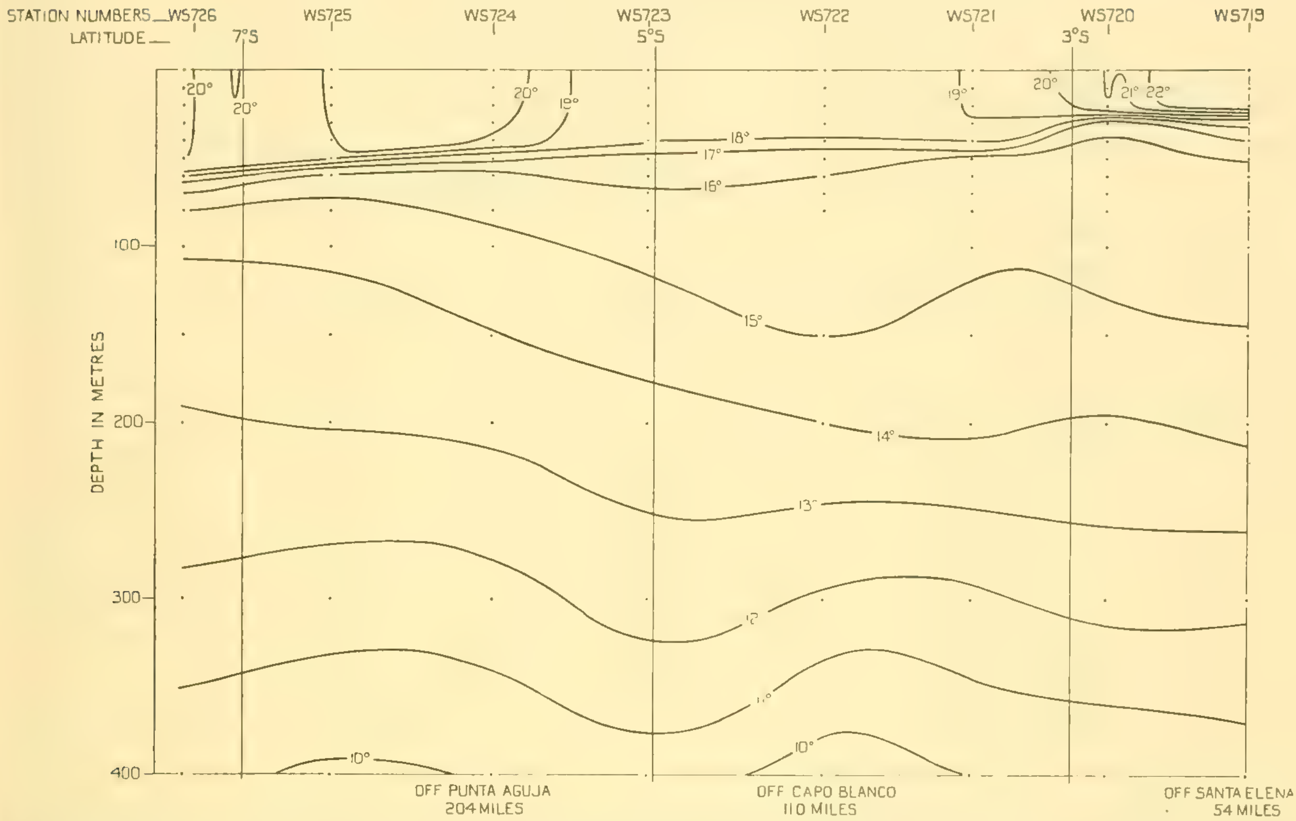

Fig. 69. Distribution of temperature (° C.). Section of the current as it leaves the Peruvian coast on its way to the Galapagos Islands, August 1–4. The position of this section is shown in Fig. 2; the corresponding salinity section, in Fig. 49.

plants indigenous to regions north of the Rio Bio-Bio have been washed up at Corral, and that this has been accepted as evidence of a southerly flowing current.

Reference to the seasonal data given in Table IX (p. 172) shows that during winter the surface temperatures on the west coast had experienced a decline everywhere except in the latitudes 34–39° S, but that here from May to September the temperature had risen. As this is within the monsoon area, we may infer this rise to have followed an alteration in the direction of surface drift. No widespread northerly drift on this coast has been found unattended by upwelling and the May temperatures may still have borne the impress of the cooling effects of the southerly winds of summer: but with the arrival, during the winter months, of the monsoon from the north, the surface drift probably became southerly and upwelling automatically came to a stop; the surface temperature rose, and this has shown itself in spite of the advance of winter.

According to these observations, the southern limit of the northerly current varies with season, and with it the upwelling characteristic of the Peru Coastal Current. According to Table IX, the surface temperature south of 40° S shows no seasonal anomaly, and this water may be regarded as belonging to the Cape Horn Current. The extreme southern limit of the Peru Coastal Current may therefore be placed at 40–41° S, which falls within a degree of Mossman's meteorological division.

NORTHERN BOUNDARY

From the wedge-shaped area of cool water over the tract extending westwards from the Piura coast towards the Equator where the Peru Coastal Current is on its way to the South Equatorial Current, Schott (1931) deduces a divergence line along which upwelling occurs far out to sea. Water north of the line remains in the South Equatorial Current, water deflected to the south mixes with the warmer South Pacific.

This interpretation may explain the data recorded in Fig. 16, which are themselves too few to illustrate the conditions described by Schott. The bulge in the isotherms off northern Peru may represent the base of a wedge of cool water extending westwards, and it is possible that some of the water in this area has come to the surface along a divergence line extending west-north-west into the open sea. The results obtained on a line of stations cutting across this region in a north-east by north and south-west by south direction do not, however, support this (Figs. 49 and 69). At the northern end, at 54 miles off Santa Elena, the hot poorly saline Equatorial Counter-current overlays water which is essentially similar to subtropical water in the Peru Current. Most of the surface water over the rest of the section is cool water of 19° C. and less: the warm-water wedge is entered between lat. 5° S and lat. 7° S, and here temperature is higher than 20° C. The isotherm of 18° C. maintains a more or less constant depth between 40 and 50 m. If the cooler water in the middle of the section was welling up to the surface, it is natural to expect the water at 40 m. to be involved, and the isotherms of 18 and 17° C. would betray upward movement in this region, and since this does not occur it may be doubted if upwelling is in progress except close to the shore. Conditions may be different farther to the west where divergence may be more active.

The northern boundary of the Peru Coastal Current during the present survey as shown by the S-shaped line of convergence between it and the Equatorial Counter-current is noted in Figs. 70 and 71. Like the southern boundary, this is liable to vary (Schott, 1931).

COMPARISON OF NORMAL AND ABNORMAL CONDITIONS ON THE WEST COAST

CLIMATE

On earlier pages, the normal wind on the west coast has been shown to be the south-east trade, modified locally as a south wind, or as a sea-breeze, the *virazon*. These winds reach a fairly high degree of saturation (80 per cent), yet as they originate from a high-pressure centre, and blow from higher to lower latitude, they are essentially drying winds; and as they enter the upwelling zone, condensation seldom amounts to more than the production of *garua* or of coastal cloud. Where the moisture capacity is increased by the higher inland temperature, and possibly also by admixture with drier inland air, the coastal cloud vanishes and the desert character of the west coast is preserved (Bowman, 1916). The persistence for thousands of years of Chilean saltpetre deposits is often cited as proof of the extreme aridity of the coastal deserts. The contrast noted by Darwin (p. 109) between this and other climatic regions of South America is illustrated in Plate XIV.

Meteorological conditions reach their greatest abnormality after the summer solstice, when, as pointed out on p. 205, the north-east trades enter the southern hemisphere and approach the Peruvian coast as a north-west monsoon. In exceptional years these bring torrential rains. On this coast rain is so seldom seen that the majority of houses, the Lima cathedral included, are built of mud; and since rivers are few and there is little vegetation to hold the soil together, rains are unusually destructive.

EL NIÑO

The *Niño* counter-current is shown by Schott (1931) to be a consequence of the northerly winds. References to it are made on pp. 158 and 205, and we shall do no more here than summarize its effects in abnormal years. In place of the cool Peru Current diverging from the shore, hot poorly saline water of the Equatorial Counter-current flows southwards and converges with it. The rise in temperature kills fish and plankton which then decompose and emit sulphuretted hydrogen on an enormous scale. This is the "Callao Painter" and it blackens the paintwork of ships lying in harbour (Raimondi, 1891), and on one occasion Chilean troops of occupation are said to have been called out to inter miles of putrifying organisms on the beach. At the same time and no less serious, the guano birds lose their food. Many die of disease and starvation, and others fly southwards in search of food, forsaking their nests and leaving the young to perish. This loss to the guano industry is said to run into thousands of pounds. In abnormal years, *El Niño* may reach as far south as Pisco, and the months of January to March are usually given for its occurrence.

AGUAJE

Under "Irregularities of the Current", p. 216, attention has been drawn to observations made by Lavalle (1924) on a warm counter-current which appears off the Peruvian coast from April to July, well after the retreat of *El Niño*. In its effects, it bears close

resemblance to *El Niño*, since contact of its warmer water with the cool coastal water may kill fish and plankton, and may even result in the emigration of guano birds. Such changes in the surface water are known locally by the name of *aguaje* and are usually

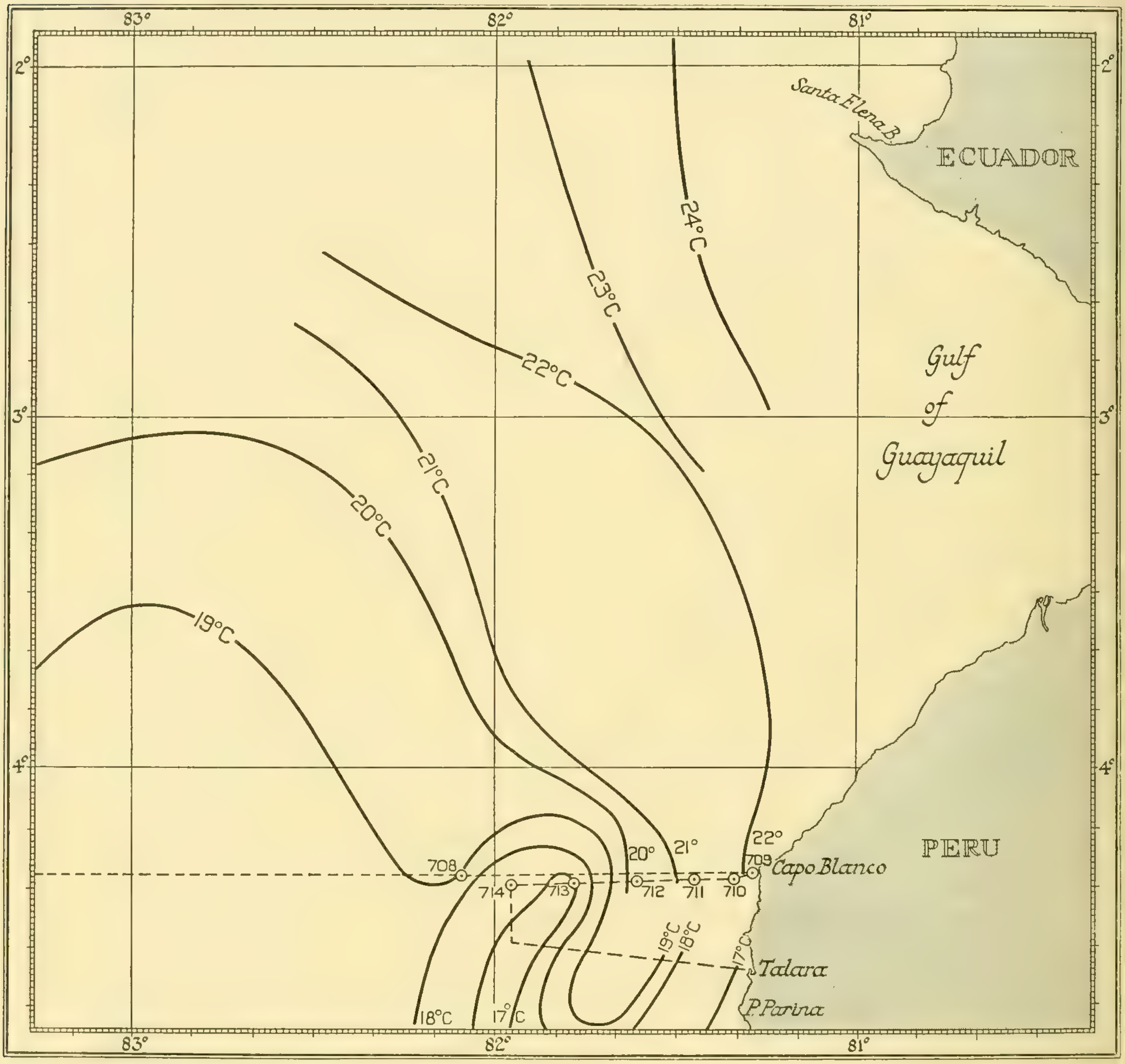

Fig. 70. Capo Blanco. Track of R.R.S. 'William Scoresby', July 24–26. From St. WS 709 to 714 course maintained 270°.

accompanied by changes of colour and by liberation of hydrogen sulphide. Thus the name *aguaje* has been used synonymously with *el Pintor*.

Stiglich (1925) gives a detailed account of the various kinds of *aguaje* known, with especial reference to their colour and to the circumstances in which they occur. In this description, much of which is gleaned from fishermen's lore, Stiglich notes that

"coloured *aguaje*"—as apart from the normal blue and green of the current—is usually red or yellow and is associated with warm water. Water which is the most coloured is said to show most movement; it sometimes attains great intensity and each time it

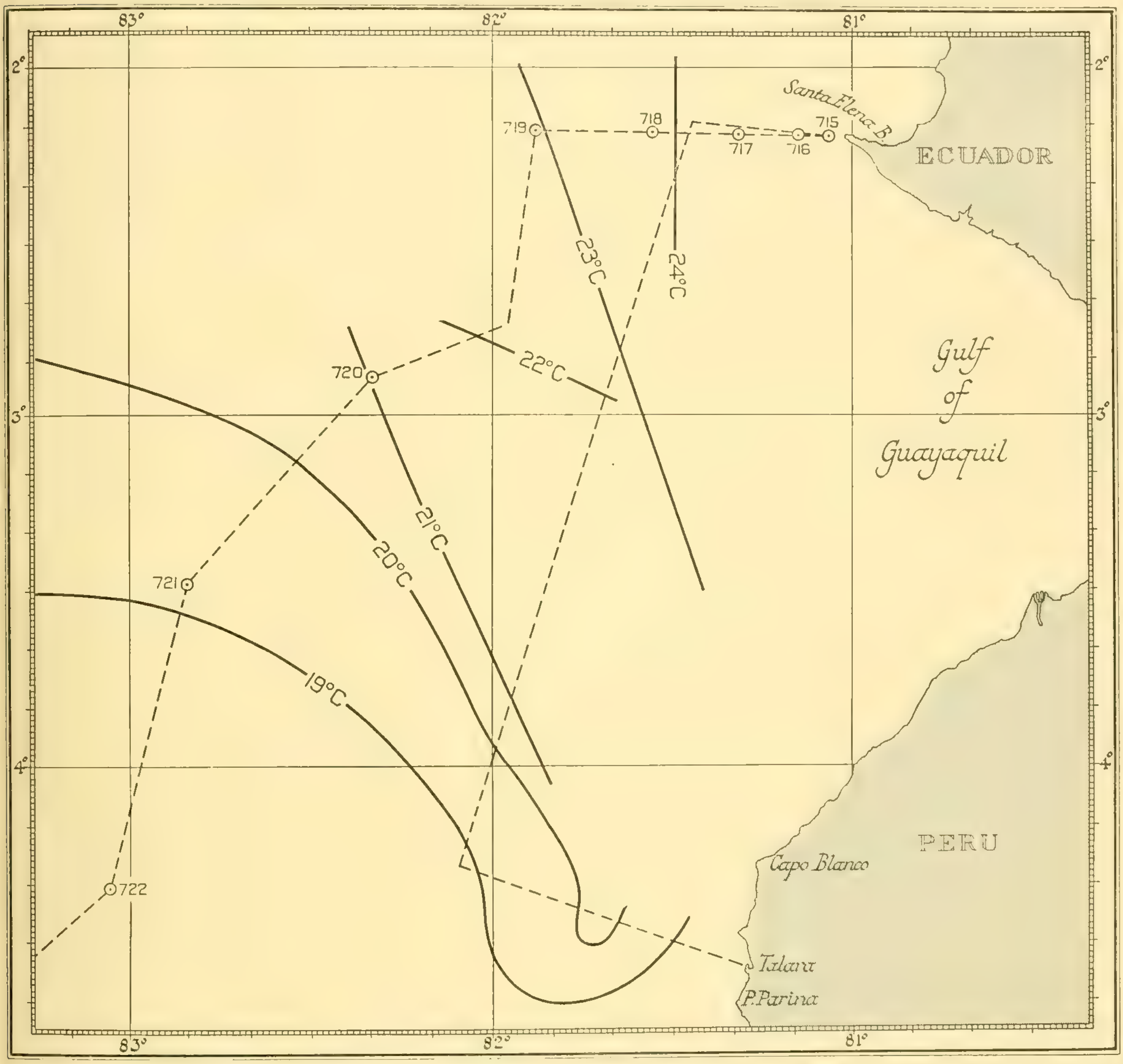

Fig. 71. Santa Elena and the Gulf of Guayaquil. Track of the ship, July 30–August 2. From St. WS 715 to 719 course maintained 270°.

reaches the beach, becomes redder, forming eddies by the shore. The fish, and especially corvina, collect in these eddies. When *aguaje* draws off, the fish remain stupefied near the beach and with them all other fish with their food—shrimps, octopuses, other molluscs, sea urchins, and various other animals. Red *aguaje* may go away leaving the water frothy. Fishermen say that fish washed up on the beach are poisonous and produce a

variety of complaints varying from headache, stomachache, dreams, and seasickness to feeblemindedness.

These observations are sufficient to suggest that the more unusual of the colours met with by us, namely, the bright salmon at Pisco Harbour, the rusty brown south of Callao, and perhaps the khaki near the Guañape Islands, may all be associated with this phenomenon (Plate XVI, figs. 6, 7 and 11). In particular, our observation of rusty brown foam (p. 174) corresponds closely to the remark made above that red *aguaje* may go away leaving the water frothy. The three observations of abnormally discoloured water met with by us were in contiguous localities: at Pisco the water had a temperature of 19·10° C., and at Callao and at the Guañape Islands the warm wedge was converging with the coast (pp. 192 and 209). Moreover, reasons are given on pp. 216–18 for considering that the counter-current causing *aguaje*, described by Lavalle, is identifiable in principle with the northern of the two wedges of the present survey. Our failure to notice unpleasant smell and dead fish might not be significant if we were late upon the scene, or if the *aguaje* were slight.

Our observation that the orange-coloured water at Pisco contained quantities of a flagellate with red pigment (p. 173), together with the stimulating papers of Hornell (1917) and Hart (1934), provide much food for speculating on the causes of the *aguaje* phenomenon. The parallelism between the phenomena of *Karanir*, *Sennir* and *Kedunir* on the Malabar coast and of *aguaje* on the Peruvian coast may be shown by the following extracts from Hornell's paper:

...all Malabar fishermen whom I have questioned agree in saying that every year after the passing of the rainy season and the subsidence of the south-west monsoon, if there be a continuance of fine weather for a week or ten days, with plenty of sunshine, and a weak coastal current, the water inshore becomes turbid and discoloured, brownish or reddish in tint; that this water has such poisonous effects upon fish that large numbers become affected and eventually die. The first effect of the poison is to make the fish sluggish and at this stage, as I have myself seen, boys and men crowd to the shore and make great hauls of the dying fish. Fishermen further state that if favourable conditions continue, the colour of this foul water changes and becomes distinctly redder, and emits a stench so strong as to be almost unbearable; when this occurs they state that the poisonous influence increases and fishes of kinds not affected during the first onset of the poison, die and are cast ashore. They agree fairly generally in stating that sardines are seldom affected in any quantity, but some men have told me that on two or three occasions, separated by long intervals, they have seen widespread sardine mortality from this cause; in these cases the sea was covered for miles with dead and dying sardines in enormous multitudes.

Hornell notes instances of water discoloured by other organisms, but concludes that in almost all cases of widespread fish mortality the discoloration was due to a swarming of euglenids to the virtual exclusion of all other organisms. He notes that bottom-living fish and invertebrates are also cast ashore; and he also notes that many of the patches of putrefying sardines were reduced to mere frothy ochreous yellow bacterial scums.

Similar instances of widespread fish mortality with discoloured water have been reported from Japan (Nishikawa, 1901) and South Africa (Gilchrist, 1914), though in neither were the organisms producing discoloration identified with certainty. In

Saldanha Bay (South Africa) the conditions had been preceded by a spell of north-west wind which may be presumed to have driven warm water against the coast. In Japan and India, fine calm weather with plenty of sunshine was the rule.

Warm surface temperatures, then, seem an essential in the production of discoloured water and fish mortality, though the activity of the surface currents mentioned by Stiglich, if this is accurate, does not tally exactly with the quiet conditions described by the others. In the writer's experience, discoloration was found where the water was inclined to be sluggish, at Pisco, Callao and the Guañape Islands, but it was not found at Arica where a strong inshore current prevented stagnancy. Whether the larger animals are killed by oxygen want which might arise in a variety of ways in such densely inhabited waters as the Peru Current, or whether from direct contact with the swarming nannoplankton, has not been determined.

Hart's observation that the ciliate *Mesodinium* swarms and discolours water under calm conditions is very similar to the above; and that it seems to be cosmopolitan (Paulsen, 1934; Clemens, 1935) opens the possibility that this organism too may be a member of the Peru Current plankton. Although it has not been shown a cause of fish mortality, its swarming if not producing a red, might when scattered produce a khaki colour similar to that figured in Plate XVI, fig. 11. As it disintegrates in bright light and in formalin, it would have escaped record in our catches.

The conclusion may be drawn that the phenomenon of *aguaje* occurs in either normal or abnormal meteorological or hydrological conditions. When brought about by *El Niño*, it is obviously contributing to the abnormal conditions then extant. At other times of the year, it is probably induced in normal meteorological conditions as a result of the convergence of a warm wedge with the coast. *Aguaje*, further, appears to show every degree of intensity: from slight discoloration with relatively little destruction of marine life, to the extremes produced during a severe invasion of *El Niño*.

Whereas in normal conditions *aguaje* may be traced to the convergence of an oceanic counter-current with the coast, the causes underlying this convergence are obscure. The importance of the anticyclonic swirls cannot be doubted: at the same time, the prominence of the *virazon* not only at Pisco, but at Callao and the Guañape Islands, may be significant (cf. Fig. 63 with Figs. 4 and 35 and Appendix IV, pp. 259–60).

MORTALITY OF SQUIDS ON THE CHILEAN COAST

We may consider whether the annual stranding of *Dosidicus gigas* in enormous numbers on the Chilean coast can be ascribed to the above phenomena. D'Orbigny (1835–43) writes of it as follows:

> Nous avons vu la mer couverte de débris d'Ommastrèphes, surtout aux mois de Février et de Mars, en approchant des côtes du Chili par 33 degrés de latitude sud; et, à la même époque, nous en avons vu jetés en grand nombre, encore vivans, à la côte de Valparaiso, sur toute celle du Chili, de la Bolivia et du Perou, à Cobija, au 23e degré de latitude sud, puis au port d'Arica. Là il y en avait tant, que la police s'était vue forcée, dans l'intérêt sanitaire du pays, ordinairement insalubre, de faire recueillir les cadavres de ces animaux, dont la putréfaction pouvait rendre l'air plus malsain encore.

Whereas February to April corresponds closely with the season of *El Niño*, this counter-current has never been recorded south of Pisco: the squids on the other hand do not appear to be stranded north of Arica.

According to Wilhelm (1930) the squids enter the harbour alive and vigorous, and he tells of a coasting steamer which meeting with a shoal in the open sea was unable to head it off from Talcahuano Bay. His observations suggest that the animals are killed as a result of battering against rocks and the quayside. The ovaries were spent, but since the females are accompanied by males, immature individuals, and sometimes by hake (*Merluccius gayi*), Wilhelm draws the tentative conclusion that the squids may have come inshore to feed.

The squids had been in Talcahuano a week or two and were already advanced in decomposition when our ship arrived. At that date, the plankton in the bay showed no signs of having been killed and water was not discoloured. We are therefore in agreement with Wilhelm, that on the evidence at present available this migration is more likely to have a biological than a hydrological cause.

COMPARISON OF CONDITIONS ON THE EAST AND WEST COASTS

The further significance of conditions in the Peru Coastal Current may be appreciated by comparing the west and east coasts of South America. Marine life on the Patagonian continental shelf is relatively poorer. The area is bathed by the Falkland Current which flows past the Falkland Islands northwards towards the South American coast, in compensation, it is believed, for the Brazil Current, as the latter is deflected eastwards. The Falkland Current thus converges with the coast, and although considerable vertical mixing takes place over the Patagonian shelf, the circulation may be expected to share some of the characteristics of a closed system.

On the west coast, on the other hand, the Peru Coastal Current is essentially a single-sided divergence line, and waters of different character, on the one hand from the deep, on the other from the surface, are being constantly mixed together, drawn off, and their place taken by fresh supplies. That areas of mixture are frequently of especial fertility for the production of plankton has been emphasized by Hardy (1935) with reference to the rich plankton found off South Georgia, where the waters of Weddell Sea and Bellingshausen Sea origin mix.

The importance of mixture may be seen in the Labrador Current. It compensates for the Gulf Stream as the latter deflects eastward, and it has in consequence been regarded as the analogue of the Falkland Current. The Labrador Current also converges with the coast, yet the fisheries of the Newfoundland Banks are the symbol of very fertile conditions. This finds a ready explanation when it is remembered that the Labrador Current is not homologous with the Falkland Current. The Labrador Current, having an Arctic origin, shares the fertility of polar seas, whereas the Falkland Current is not Antarctic but sub-Antarctic, is an arm of the West Wind Drift and has not experienced the vertical mixing of ice-laden water.

SUMMARY

The Royal Research Ship 'William Scoresby' visited the west coast in the southern winter of 1931, the object of her enquiry being the Peru Coastal Current. Observations on temperature, salinity, oxygen and phosphate from surface to bottom, and collections of phyto- and zooplankton in the upper layers were undertaken as a routine.

DEVIATION OF COASTAL WINDS

Wind observations are analysed and compared with earlier records (pp. 121–4 and Fig. 4). North of 40° S, coastal winds blow parallel to the shore, showing a deviation from the south-east direction typical of this sector of the South Pacific anticyclonic high-pressure area. The importance of the Andean barrier is stressed. Some evidence was found of the onshore breeze, known locally as the *virazon*, another coastal modification of importance. Results show that the survey was undertaken in meteorological conditions which may be regarded as normal.

NORTHERLY CURRENT

Though irregular in its distribution, surface current was found to have a more northerly course close to the coast than in the open sea (pp. 133, 189 and 190). Likewise the subtropical convergence was found to curve northward as it approached the coast (see below).

WESTERLY SET

Farther from the coast, northerly drift lessened but only in places was westerly set found to be pronounced (p. 190, Fig. 14). Westerly set is inferred to be widespread in the ocean at large by an unfailing appearance of upwelling near the coast, even under very diverse meteorological and hydrological conditions.

VERTICAL CURRENTS

Local influences

An attempt is made to relate these diverse conditions to the volume of upwelling which was also found to vary. The effect of local influences is considered, and the onset of heavy wind from the appropriate quarter is shown to be responsible for an unusual lowering of inshore temperatures (pp. 140, 143, 148–56, 169).

Subsidence

Instances of a reversal of such wind and a rise in temperature have led to subsidence. Examples at Antofagasta, Callao and the Guañape Islands are given on pp. 143–5, and 153–6; while other examples may be found on pp. 169–71. Evidence for the theory is examined critically (p. 213). Such subsidence is not supposed peculiar to the hydrology of this coast, but may be a principle of wide application.

Seiche action

The question of distinguishing between upwelling and subsidence on the one hand, and seiche action on the other, is considered. Definite evidence of the existence of seiches in the Pacific has not been found, but the possibility that our results may lend themselves to this interpretation is pointed out (p. 212).

Latitude

No disparity of upwelling was noted between the Chilean and Peruvian coasts, although the surface layers are more homogeneous, and the current is stronger off Peru. An agent equalizing these factors is possibly the differential effect of latitude (p. 211). Neither sea-bottom contour nor coast-line trend appeared to have any effect (pp. 202–4).

Sinking of newly mixed water

The essential differences between the sinking of water by this mechanism and by subsidence are considered (p. 214). The process seemed to have been in progress off Caldera on the outer edge of the upwelling zone, and to have been brought on by recent northerly wind (p. 140). It is presumed to have far-reaching importance in the mixing of upper and lower layers and to occur most frequently in the neighbourhood of the subtropical convergence.

DISTRIBUTION OF WATER MASSES

Surface

The convergence of sub-Antarctic and subtropical water which lies along the 30–32° S parallels in 95–105° W, curves northwards on approaching the Chilean coast and was found as far north as 24–26° S, in 70–71° W (Table V and Fig. 42, pp. 160 and 161). As both these water-masses participate in its northward flow, the Peru Coastal Current crosses a convergence.

Beneath the surface

At this convergence, the sub-Antarctic water sinks and is shown to send an arm northwards for some 10° of latitude beneath the subtropical layer (p. 161 and Fig. 42); and was welling up to the surface at three localities (Figs. 20, 22 and 43). At a deeper level, a more saline and comparatively warm return current of subtropical water (poor in oxygen) was drawn southwards, and was welling up to the surface at San Juan, Antofagasta, and possibly Cape Carranza, centres of exceptional activity (pp. 162–3, Figs. 18, 24 and 45).

HORIZONTAL SURFACE CURRENTS

Highly saline tropical water (> 36·00 ‰) was not met within the limits of the Coastal Current, but a highly saline wedge of warm water lay at some distance off the coast both off southern and northern Peru (Figs. 16 and 63). Continuity in a counter-current just here is not easily explained: the depth of its maximum salinity is shown to

increase towards the south as it would if its origin lay at the surface westwards of the region surveyed (p. 161, Table V). Convergence of this warm wedge with the coast at two points (Callao and Arica) becomes significant when correlated with circumstantial evidence.

Evidence of anticyclonic swirls

(1) Northerly coastal drift was of most account at two localities, off San Juan and off northern Peru; i.e. where the wedge was farthest from the shore (Table I). (2) Surface temperatures depressed over a wide area round these points showed them to be upwelling centres (Fig. 16). (3) Here also southerly drift was noted offshore (Table I and Fig. 14). (4) Off northern Peru, westerly set was marked. The probable existence off the Peruvian coast of two large anticyclonic swirls is thereby demonstrated (pp. 191–2 and Fig. 63), and receives confirmation from temperature and current relationship of the wedges at San Juan and Callao (p. 192, Figs. on pp. 149 and 165). The warm wedges converging with the coast to the south of their respective upwelling centres appear thus to be oceanic currents of compensation.

Permanence of anticyclonic swirls

Data of earlier observers are analysed. The agreement between (1) Schott's upwelling centres and variations in volume of upwelling already noted; (2) our records of drift and those, notably, of Garcia, Ray, Dinklage and Somerville; and (3) the dual convergence of warm water with the coast and the counter-currents reported by the 'Mentor', Lavalle, and Stiglich; indicate that the anticyclonic whirls are either permanent or recurrent.

Cyclonic eddies

Inshore counter-currents, apparently making a series of small-scale coastal eddies, were frequently recorded (p. 191). At Caldera and Bahia Herradura eddies are presumed to have resulted from a southward flow inshore of water deflected east, flowing in compensation for a local deflection of the offshore water west. At Caldera an eddy-like appearance beneath the surface was given by sinking water (Figs. 8 and 23).

HORIZONTAL SUBSURFACE CURRENTS

Below the surface the two layers already noted—the arm of sub-Antarctic above, and the subtropical return current below—are shown to have a coastal nature which is emphasized with special reference to conditions in mid-Pacific and mid-Atlantic (pp. 161, 194 and 200). The modifications they introduce into the arrangement of coastal water-masses shows them to be subsurface currents compensatory for water drawn to the surface by upwelling.

SURFACE SALINITY OF THE COASTAL CURRENT

The fact that upwelled water has a higher salinity than the surface of the adjacent ocean in the south of the region, but is less saline than the adjacent ocean in the rest of the region, is attributed to these subsurface currents of compensation (pp. 162–3).

DEPTH AFFECTED BY UPWELLING

The trend of isotherms and isohalines below the surface is shown to be influenced not only by upwelling water but by the structure of the compensating currents. The determination of the depth from which upwelling takes place is confused by this second factor. A minimum value of 40 m., a mean of 133 m., and a maximum of 360 m. are suggested (pp. 200–1).

ORGANIC PRODUCTION

An attempt is made to ascertain the major effects of these hydrological processes on the life of the region. Areas of exceptional upwelling are first shown to be exceptionally rich in nutrient salts (p. 180, and Figs. 54, 57 and 58); and then to have a high phytoplankton and zooplankton content (Table XIII). A new method of demonstrating the consumption of nutrient salts by the phytoplankton is tentatively considered (pp. 184–9). The results are shown to be in accord with what is known of the cycle of organic production in other parts of the world: and they have been used to infer the conditions in the area at periods earlier than the date of our visit (pp. 135, 186, 188, 201, 220).

Regional fertility

The permanence of upwelling centres suggests that these are perennially more fertile than other parts of the coast: this and the paucity of phytoplankton in the warm wedges and at their points of convergence with the coast (Callao and Arica, Appendix I), suggest that the fertility of a locality is bound up with the position relative to it of the anticyclonic swirls. At the same time the unfailing appearance of upwelling, even at such localities of convergence, suggests that all localities are potentially fertile (pp. 211 and 219).

COLOUR OF THE CURRENT

The average bulk of phytoplankton varied at different distances from the shore in a way suggesting that the area has not been adequately sampled. Nevertheless there were signs that on average the yield is no heavier in the upwelling zone than at distances up to 100 miles from the coast (Table XI, pp. 178–9). The green colour of the current, on the other hand, was seldom found to extend beyond 30 miles from the shore. A hypothetical explanation is advanced which relates the green colour to the zone where illumination is lessened by cloud (p. 222).

Discoloration

Discoloration due to colours of purely animal nature appear to be rare. Between Sts. WS 656 and 657 such a patch of brick red was discovered, due to a swarm of euphausian cyrtopias. The yellow off Punta Aguja and the salmon colour at Pisco were attributable to vegetable pigments, the former algal (of a symbiotic colonial radiolarian), the latter directly or indirectly flagellate (pp. 174 and 173).

Grounds are adduced for identifying the colours of very unusual appearance met with off Pisco, Callao and the Guañape Islands (Plate XVI, figs. 6, 7 and 11) with the *aguaje* phenomenon rather than with the appearance at the surface of normal animal plankton (pp. 222 and 229–33).

AGUAJE

A condition of the surface water in which discoloration, fish mortality and liberation of hydrogen sulphide take a leading part, is known as *aguaje*. Compared with other records, our results support the view that *aguaje* may result in coastal water from a sudden rise in temperature. Under the apparently normal conditions of the present survey, it was found to coincide with the northern anticyclonic swirl at those points where its oceanic limb, the warm wedge, was converging with the coast. It appears also to be brought on by convergence of the abnormal counter-current known as *El Niño*. *Aguaje*, although an abnormal phenomenon in the sense that it may upset the balance of nature, is therefore liable to occur in either normal or abnormal conditions (pp. 229–33). The nature of *aguaje* is summarized: its effects are shown to vary from the mild met with in 1931, to the extremes which kill plankton and fish, cause the guano birds to migrate, and produce the "Callao Painter".

MORTALITY OF SQUIDS ON THE CHILEAN COAST

Large quantities believed to be *Dosidicus gigas* (Orbigny) were found washed up in Talcahuano harbour, but no connection could be found between them and the abnormal phenomena noted on the Peruvian coast (p. 233).

BOUNDARY OF THE PERU COASTAL CURRENT

Coastal and oceanic conditions contrasted

Results summarized in foregoing paragraphs have shown the more important biological and hydrological characteristics of the coastal current to be attributable to upwelling of lower layers and their mixture with surface water masses. Equivalent characteristics of the open ocean are contrasted in Table XXII.

The distribution of surface isotherms seems the most comprehensive characteristic, for isotherms usually run east and west parallel to latitude, but they change direction under the preponderating influence of upwelled water and run parallel to the coast. If their change of direction is taken as the western boundary, the whole area surveyed by the 'William Scoresby' lies within the Peru Coastal Current (Figs. 16 and 17). An arbitrary boundary is suggested on the basis of Schott and Schu's chart of mean annual isotherms (Fig. 68).

Northern boundary and the Equatorial Counter-current

The northern boundary is shown to be easily recognizable as the convergence of cool upwelled water of moderate salinity (> 35·00 ‰) with the warm poorly saline

(< 33·00 ‰) Equatorial Counter-current (Figs. 42 and 70). The boundary was crossed, off Capo Blanco, but had altered considerably within five days.

Table XXII. *The Peru Coastal Current and the Peru Oceanic Current compared*

	Inshore conditions	Offshore conditions
Currents	Current northerly and counter-currents frequent Vertical currents lead to vertical mixing	Drift mainly westerly Vertical mixing checked by a discontinuity layer
Temperature	Low Surface isotherms run north and south	High Isotherms run east and west
Salinity	South of subtropical convergence: Low North of subtropical convergence: High	Lower Higher
Nutrient salts	Constantly replenished	Depleted
Colour	Green, etc.	Blue or indigo
Marine life	Plankton abundant and largely littoral in character Animals of economic importance, plentiful	Plankton oceanic Animals of economic importance, rare or absent

Southern boundary and the Cape Horn Current

Seasonal changes have been used, with fair precision it is believed, to determine the southern limits of the Peru Coastal Current. Surface temperature on the west coast, from 8 to 47° S, declined with advance of winter, in all but the parallels of 34–39° S (Table IX). This anomalous rise becomes intelligible on the hypothesis that a former period of active upwelling had existed between these parallels, a hypothesis receiving support from established meteorological facts (pp. 226 and 227). These parallels come under the influence of the Chilean monsoon and after their advent, a cessation of upwelling may be presumed.

The southern limits of the Coastal Current, identified as the southernmost upwelling centre, is consequently placed in 40° S, within a degree of Mossman's division between cyclonic and anti-cyclonic wind systems. In winter months, however, the southern limit may be as far north as 33° S. It therefore varies with season. Southwards of 40° S surface temperatures show no seasonal anomaly; this has been identified as the Cape Horn Current.

CONDITIONS ON THE EAST COAST AND WEST COAST COMPARED

The essential characteristics of the Peru Coastal Current and its wealth of fauna and flora are immediately traceable to the divergence of surface water from the west coast. This is the means by which nutrient salts are brought to the surface, and its importance is made evident by brief reference to conditions on the east coast of South America.

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APPENDIX I

Volumes of phytoplankton (c.c.). Table of provisional measurements

Cape Carranza

WS 591	< 25[1]	
592	< 25[6]	
593	25[4]	
594	**75**[4]	
595	< **75**	
596	< 25	
597	> **150**	
598	> **150**	
599	> **100**	
600	> **125**	
601	> **150**	

Pichidanque Bay

WS 602	< 25	V. few
603	< 25	
604	< 25	
605	< 25	
610	< 25	
609	< 25	
608	< 50	
606	< 25	
607	< 25	

Caldera

WS 613	< 25	
614	< **50**	
615	> **25**	
616	< 25	
618	—	
617	< 25	
620	—	
619	**25**	
612	> **25**	

Antofagasta (south)

WS 622	< 25	Diatoms almost absent
623	< 25	
624	< 25	
625	< **100**	
626	< **75**	
627	> **150**	
628	—	
630	< 25	Few
629	< 25	Few

Antofagasta (north)

WS 631	< 25	
632	< 25	
633	< 25	V. few diatoms
634	< 25	
635	< 25	

Arica

WS 640	< 25[8]	
641	< 25	Few and practically absent
642	< 25	
643	< 25	
639	< 25	
638	< 25	

San Juan

WS 647	< **25**[7]	
648	< **25**	
649	**25**	
650	< **25**	Decrease
651	< 25	Gt. diminution
646	< 25	V. few
657	< **75**	
656	> **300**	
655	> **150**	
652	< 25	
654	< 25	Few
653	< 25	

Callao (July)

WS 663	< 25[6]	
644	< 25[10]	
665	< 25	
666	< 25	Few and almost absent
667	< 25	
671	> 25	
670	> 25	
669	> 50	
668	< 25	

Callao (August)

WS 728	> **100**	
729	< **75**	
730	—	
731	25	V. gt. dim.
732	< **50**	
733	< **50**	
734	< **100**	

Guañape Islands

WS 675	—	
676	< 25[1]	
677	< 25[5]	Few
678	< 25[5]	
679	< 25[6]	
680	< 50[9]	Amphipoda
681	< 25	
682	< 25	Diatoms almost absent
674	< 25	
686	< 50	

Lobos Islands

WS 691	< **25**[6]	
690	< **25**[9]	
692	< 25[1]	
693	< 25[3]	
694	< 25	Few
695	< 25	V. few
696	< 25	
689	< 25	Diatoms almost absent
688	< 25	
687	< 25	

Punta Aguja

WS 697	> **50**[6]	
698	> **250**[6]	
699	**390**	
700	< **25**	
701	< 25	Absent
702	< 50	Few
703	< 25	
704	< 25	V. few
705	< 50	
706	< 50	
707	< 25	

Capo Blanco

WS 709	> **50**[2]	
710	< 50[7]	Gt. diminution
711	< 100	Absent
712	50	Diatoms practically absent
713	< 50	
714	< 50	
708	< 100	
722	> 50	

The table includes only the stations on lines normal to the coast. The data represent the settled volume of all organisms taken by the gran net hauled vertically from a depth of 100 m. to the surface except where otherwise indicated. The measurements are to the nearest 25 c.c. Figures in heavy type denote suspected patches of phytoplankton.

[1] N 50 H depth 0–5 m.
[2] N 50 V „ 30–0 m.
[3] „ „ 35–0 m.
[4] N 50 V depth 40–0 m.
[5] „ „ 45–0 m.
[6] „ „ 50–0 m.
[7] „ „ 60–0 m.
[8] N 50 V depth 80–0 m.
[9] „ „ 90–0 m.
[10] „ „ 95–0 m.

APPENDIX II

A partial list of contributors to the literature of the Peru Coastal Current

Contributor	Ship	Year of observation	Year of publication
Leon, Pedro de Cieza de	—	1547–	1553
Zarate, Augustine de	—	1543–50	1555
Acosta, J. de	—	1571–85	1608
Fletcher, F.	'Pellican'	1578–79	1628
Hawkins, Sir R.	'Dainty'	1594	1622
Ovalle, Alonzo	—	—	1649
Dampier, W.	'Revenge'	1684	1703
Funnel, W.	'St George'	1704	1729
Frezier, A. F.	'S. Joseph', 'Mary Anne', etc.	1712–14	1716
Betagh, W.	'Speedwell'	1720	—
Walter, R.	'Centurion'	1741	1748
Ulloa, A. de	'Incendio', 'Rosa', etc.	1740–44	1748
Colnett, J.	'Rattler'	1793–94	1798
Unanue, J. H.	—	—	1806
Romme, Ch.	—	—	1806
Humboldt, Alexander H. F. von	—	1802	1810
	—	—	1811
	—	—	1826
Colmenares, J. I.	'Limeño'	1805–08	—
Hall, B.	'Conway'	1820–22	1825
Lartigue, J.	'La Clorinde'	1822–23	1827
Duperrey, L. I.	'Coquille'	1823	1829
Harmssen, J. H.	'Mentor'	1823	See
	'Princesse Louise'	1826–27	Berghaus 1842
Dirckinck de Holmfeldt	—	1825	See Humboldt 1826
Bougainville, H. Y. P. P. de	'Thetis' and 'L'Espérance'	1825	1837
Beechey, F. W.	'Blossom'	1825–28	1831
King, P. P.	'Adventure'	1829	1850
Meyen, F. J. F.	'Princesse Louise'	1831	See
Wendt, J. W.	'Princesse Louise'	1831 and 1833	Berghaus 1842
Reynolds, J. N.	'Potomac'	1832–33	1835
Rodbertus, J. T.	'Princesse Louise'	1837 and 1839	See Berghaus 1842
Berghaus, H.	—	—	1837
	—	—	1839
	('Mentor', 'Princesse Louise')	(1823–39)	1842
	—	—	1852
Fitz-Roy, R.	'Beagle'	1835	1839
Darwin, C.	'Beagle'	1835	1839
Darondeau, B. and Chevalier, Y. E.	'Bonite'	1836	1840
Tessan, U. de	'Vénus'	1837–38	1844
Arago, D. F. J.	('Vénus')	(1837–38)	1840
Belcher, E.	'Sulphur'	1838	1843
Wilkes, C.	'Vincennes'	1839	1845
Johnstone, A. K.	—	—	1848, 1850, 1856
Seemann, B.	'Herald'	1845	1853
Woolridge, O.	'Spy'	1847	See Raimondi 1891
Findlay, A. G.	—	—	1853
Maury, M. F.	—	—	1855
Kerhallet, C. P. de	—	—	1856

APPENDIX II (*cont.*)

Contributor	Ship	Year of observation	Year of publication
Perez-Rosales, V.	—	—	1857
Webber, V. A.	'Hercules'	1858	1859
Ferrel, W.	—	—	1860
Wüllerstorf-Urbair, B. von	'Novara'	1859	1862
Becher, A. B.	—	—	1864
Bent, S.	—	—	1869
Garcia y Garcia, A.	—	—	1870
Hutchinson, T. J.	—	1871–73	1873
Witte, E.	—	—	1871
	—	—	1880
Laughton, J. K.	—	—	1870
Dinklage, L. E.	'Charlotte'	1874	See Schott 1891
Wolf, Th.	—	1875	1879
Hoffmann, P.	'Moltke'	1881–83	1884
Amezaga, C. de	'Caracciola'	1882	1882
Hollmann	'Elisabeth'	1882	1882
Buchanan, J. Y.	—	1885	1886
	—	—	1910
Ray, R. C.	—	—	1890, 1896
Denker, J.	'Atalanta'	1891	See Zorell
Lubken, G.	'Ancona'	1891	See Zorell
Raimondi, D. A.	—	—	1891, 1897
Carranza, L.	—	—	1891
Carrillo, D. C. N.	—	—	1892
Official American Bulletin	—	—	1892
Eguiguren, V.	—	—	1894
Puls, C.	—	—	1895
Pezet, F. A.	—	—	1896
Smith, W. A.	—	—	1899
Melo, R.	—	—	1906
Bowers, G. M.	'Albatross'	1904–05	1906
Mossman, R. C.	—	—	1909
Krümmel, O.	—	—	1911
Lavalle, J. A., y Garcia	—	—	1917
Coker, R. E.	—	1908	1918
Bowman, I.	—	1911	1916
Chile, Derrotero de la Costa de	—	—	1918
Stiglich, G.	—	—	1918
	—	—	1925
Stolzenbach	'Karnak	1916–18	See Schott 1931
Lavalle, J. A. de	—	1917–24	1917–24
Somerville, B. T.	—	—	1923
Murphy, R. C.	—	1919–25	1923
	—	—	1925
	—	—	1926
Szyszlo, V.	—	—	1925
Oetcken, L.	'Odenwald'	1924–25	See Zorell
Goose, W.	'Wiegand'	1925	See Zorell
Hensen, O.	'Spreewald'	1925	See Zorell
Kilp, H.	'Negada'	1925	See Zorell
Kunstler	'Kellerwald'	1925	See Zorell
Piper, O.	'Planet' and 'Poseidon'	1925	See Zorell
Volquardsen	'Oldenburg'	1927	See Zorell

APPENDIX II (*cont.*)

Contributor	Ship	Year of observation	Year of publication
Gunckel, H.	—	1927	1928
Zorell, F.	('Atalanta', etc.)	(1891–1927)	1928
Thoulet, J.	('Challenger')	(1875)	1928
Schott, G.	('Charlotte')	(1874)	1891
	('Emden')	(1927)	1931
	'Nitocris'	1929	
Brooks, C. E. P.	—	—	1929
Wilhelm, O.	—	1930	1930
Sverdrup, H. U.	('Carnegie')	(1928–29)	1930
Vallaux, C.	—	—	1930
Schweigger, E. H.	—	1929–30	1931
Sheppard, G.	—	1923–	1931
Semple, W.	—	—	1931
Wilson-Barker, D.	—	—	1931
Torrico, R.	'William Scoresby'	1931	1933
Wüst, G.	—	—	1935

Note. Contributors are listed, as far as possible, in the order in which their observations were made. Ship and date in brackets indicate the expedition from which the author cited has mainly drawn his data.

APPENDIX III

Table giving date, hour, position and nomenclature of the colours in Plate XVI

Plate III Fig.	Date	Hour	Position Latitude S	Position Longitude W	Station	Colour nomenclature*			
1	11. v. 31.	0900	44° 20′	75° 57′	—	Dull blackish green	XLI	33‴	GY–G, *m*
2	7. vi. 31	1400	25° 36′	70° 39′ 30″	—		XX	44′	*l*
3	7. vi. 31	1400	25° 36′	70° 39′ 30″	—		XX	44′	*j*
4	8. vi. 31	0900	23° 32′ 36″	70° 38′ 30″	WS 622	Diamine green	VII	37	GB–G, *m*
5	9. vi. 31	1500	23° 21′ 30″	71° 28′	WS 629		VIII	46	
6	25. vi. 31	1300	13° 45′ 30″	76° 20′	WS 658	Ochraceous-salmon	XV	13′	OY–O, *b*
7	26. vi. 31	1130	12° 09′ 30″	77° 15′	Site of WS 662	With patches of	XV	14′	
						cinnamon rufous	XIV	11′	Orange, *i*
8	26. vi. 31	1230	12° 08′	77° 16′	WS 661	Porcelain blue	XXXIV	43″	G–B
9	10. vii. 31	1630	8° 19′ 30″	79° 05′ 45″	WS 677	Olivine	XXXII	35″	Green, *d*
10	10. vii. 31	1700	8° 24′ 30″	79° 03′	—	Sea green	XIX	41′	BB–G, *k*
11	10. vii. 31	1745	8° 30′ 30″	79° 00′	—		XXX	20″	*i*
12	16. vii. 31	1130	10° 33′	79° 08′	—	Deep Delft blue	XLII	45‴	BG–B, *k*
13	25. viii. 31	1400	23° 21′	75° 12′	—		VIII	46	
14	16. vii. 31	1130	10° 33′	79° 08′	—	Pale Russian blue	XLII	45‴	BG–B, *f*
15	28. viii. 31	1100	31° 12′	72° 14′	—		VIII	47	G–BB, *j*

* Ridgway, 1912.

Note. Owing to practical difficulties in the making of such records, the colours shown in Plate XVI are not always in exact correspondence with these references.

APPENDIX IV

List of observations on surface temperature and wind[1]

Date 1931	Hour	Station WS	Position		Distance offshore miles	Temp. °C.	Wind[2]	
			Latitude S	Longitude W			Direction	Force
10. v	1200		47° 19′ 30″	75° 21′	<30		ENE	2
	1600						S × E	3
	2020	587	46° 14′ 30″	75° 55′ 36″	30	11·7	S	3
	0000						SSE	5
11. v	0400						S	4
	0800		44° 28′	76° 11′	70	12·0	ESE	3–4
	1200						ESE	3–4
	1600						ESE	4
	2013	588	42° 42′	75° 21′	56	12·73	E	4
	0000						Easterly	4
12. v	0400						ESE	4–5
	0800		41° 03′ 30″	74° 10′	12	12·66	ESE	4–5
	1200						ESE	5
	1600		Corral				E × S	5
	2000						SE	2–3
	0000						ESE	5–7
15. v	0400		Corral				Easterly	1
	0800		39° 53′	73° 27′	2	9·8	SE	2
	1200		39° 13′ 36″	73° 35′ 36″	18	11·22	SE	2
	1600		38° 34′	73° 46′ 30″	13	11·19	—	0
	2009	589	38° 04′	73° 52′	22	10·67	Westerly	2
	0000		37° 34′	73° 56′	12	12·18	—	0
16. v	0337		36° 59′	73° 46′	11	11·56	SE	1
	0800		Talcahuano		11?	11·35	NE	1–2
	1200						—	0
	1400	590			0	11·2	NE	2
	2000						—	0
	0000						—	0
18. v	0400						—	0
	0800						NE × N	4
	1300	591	35° 47′	72° 39′	2·7	11·7	N × E	3
	1359	592	35° 46′	72° 42′ 30″	4·5	11·46	E	1–2
	1629	593	35° 36′	72° 44′	4·5	11·45	NW × N	2
	1752	594	35° 36′	72° 50′	9	11·69	—	0–1
	1943	595	35° 35′ 12″	72° 56′	14·5	11·62	—	0–1
	2206	596	35° 35′ 36″	73° 07′ 30″	24	11·85	—	0–1
	0000						N × E	1
19. v	0400						N	2
	0643	597	35° 39′ 42″	73° 19′ 30″	32	12·36	NNE	4
	0800						NNE	4
	1025	598	35° 43′	73° 32′	40	12·12	NNE	4
	1200						NNE	2
	1410	599	35° 41′ 30″	73° 43′	49	12·87	ESE	3

[1] The Table gives only the more important of the observations that have been made. Additional records of wind made while the ship was in harbour, and of surface temperature made between the observations here listed, are to be had on application to the Discovery Committee.

[2] Wind data are taken from the deck log book and are additional to those shortly to be published in the station list.

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position: Latitude S	Position: Longitude W	Distance offshore miles	Temp. ° C.	Wind: Direction	Wind: Force
19. v	1600						ESE	2–3
	1915	600	35° 40′	73° 55′	58·5	13·57	SW	3
20. v	0015	601	35° 30′ 30″	74° 18′	79	13·65	SSE	3
	0400						ESE	2
	0800						SE × E	2
	1200		35° 14′ 06″	72° 45′ 30″			SE × E	2
	1700		35° 02′	72° 25′	10	12·0		
	2000		34° 39′	72° 23′	18	12·35	Light airs	0–1
	0000					12·91	SE	2
21. v	0400				? 20	12·81	S	2
	0800		Valparaiso				SE × S	4
	1200						Light airs	0
	1600						,,	0
	2000						,,	0
	0000						Easterly	1–3
28. v	0400						Light airs	0
	0900		32° 40′	71° 39′	8	13·5	,,	0–1
	1300	602	32° 04′ 45″	71° 34′	0·5	14·02	SSW	2
	1502	603	32° 05′	71° 40′	5·5	14·32	SW	2
	1655	604	32° 05′	71° 45′ 30″	10·5	14·00	E	2
	2030	605	32° 05′	71° 50′	14·5	13·91	E	2
	0000					14·08	—	0–1
29. v	0400					14·39	N	1
	0745	606	32° 09′ 36″	73° 32′	101	16·2	S	3
	1200						S	2
	1600					16·38	S × W	4
	1718	607	32° 05′ 30″	74° 04′	129·5	16·42	S	4
	2000						Southerly	4
	0000					15·19	SSE	4
30. v	0440	608	31° 57′ 30″	73° 02′	74·5	14·01	S	5–6
	0800						S	6
	1115	609	31° 51′ 12″	72° 34′	51	14·25	S	5–6
	1600						S × W	5
	1840	610	31° 45′ 30″	72° 01′ 30″	24·5	14·00	S	3
	0000		31° 25′	72° 00′ 30″	19·5	13·89	—	0
31. v	0400				15	15·75	S	3
	0800					13·05	S	3
	1030		Coquimbo			13·39		
	1200						SW	2
	1600						SW	1–2
	2000						SW	1
	0000						—	0
3. vi	0400		Coquimbo				—	0
	0800						—	0
	1200						—	0
	1415				2	15·10		
	1500				2–3	14·64		

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position: Latitude S	Position: Longitude W	Distance offshore miles	Temp. ° C.	Wind: Direction	Wind: Force
3. vi	1530				5	14·42		
	1600				9	13·55	SW	1–2
	1630				12	14·58		
	1700				14	14·45		
	1800		29° 34′	71° 38′	14	13·95		
	2000	611	29° 11′	71° 42′ 30″	10	15·03	NE	2
	0000		28° 47′	71° 44′	16	15·2	NNW	1
4. vi	0400				33	14·41	SW	1–2
	0800		27° 38′ 24″	71° 56′	44	16·46	WSW	1–2
	1120	612	27° 08′ 30″	72° 01′ 30″	54	16·61	SW	3
	1600						S × E	3
	2000						SW	3
	0000						SSE	3
5. vi	0400						—	0
	0640	613	27° 05′ 30″	70° 58′	1	13·1	ESE	2
	0830	614	27° 06′ 30″	71° 00′ 42″	2	13·45	ESE	2
	1119	615	27° 05′ 30″	71° 04′	5	14·2	ESE	2
	1511	616	27° 08′	71° 10′	8·5	14·88	WNW	1–2
	1825	617	27° 09′ 30″	71° 15′ 42″	13·5	15·9	WNW	2
	2250	618	27° 09′	71° 12′ 30″	11	15·1	WNW	1
	0000						—	0
6. vi	0440	619	27° 03′ 30″	71° 30′	27	16·56	—	0
	0800						NNW	2
	1150	620	27° 04′ 30″	71° 23′	21	16·5	ENE	2
	1600						N × W	1–2
	2000						—	0–1
	0000		26° 52′	71° 43′	41·5	16·67	NNE	2
7. vi	0400		26° 28′ 25″	71° 15′ 18″	28	16·15	SE	2
	0815		26° 02′	70° 48′ 15″	8·5	15·7	S	2
	0845				7·5	16·7		
	0915				6·25	16·2		
	0930				5·5	15·68		
	0958					14·78		
	1000		25° 47′	70° 48′ 45″	5·0	14·45		
	1002					14·3		
	1015					14·38		
	1030					14·45		
	1045				5·25	14·2		
	1100					14·28		
	1115					14·39		
	1130					14·35		
	1145					14·38		
	1200					14·4	S	3
	1230		25° 28′	70° 39′	2·75	14·55		
	1300		25° 24′	70° 38′ 45″	6·75	15·28		
	1315				7·75	15·8		
	1330				8·3	16·3		
	1337					16·5		
	1345					16·7		

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position: Latitude S	Position: Longitude W	Distance offshore miles	Temp. °C.	Wind: Direction	Wind: Force
7. vi	1352					16·76		
	1400				5·75	16·79		
	1407					16·75		
	1415					16·69		
	1430					16·49		
	1445		25° 1′ 35″	70° 38′	6	16·09		
	1500					15·65		
	1515					15·90		
	1530					15·70		
	1545					16·18		
	1600				2·3	16·68	SSW	3
	1615					16·55		
	1620					16·53		
	1625					16·49		
	1630		24° 52′ 30″	70° 35′	0·5	16·30		
	1635					16·30		
	1700				3	16·31		
	1800				2·25	16·8		
	1900				3·6	17·17		
	2020	621	24° 27′ 30″	70° 43′	6	17·20	Southerly	4–5
	0000		24° 02′	71° 11′	35	17·41	S	4–5
8. vi	0400				30·5	16·69	S	4–5
	0810	622	23° 32′ 36″	70° 38′ 30″	1·3	14·10	E	4
	1029	623	23° 32′ 42″	70° 41′	2	14·14	E	4
	1315	624	23° 31′ 45″	70° 44′ 30″	4·7	14·31	S	3
	1520	625	23° 31′ 40″	70° 47′	7	13·93	S	3–4
	1735	626	23° 30′	70° 50′	9·8	14·09	S	4
	2040	627	23° 28′	70° 52′ 30″	12	15·01	S	4
	2354	628	23° 25′	70° 55′	15	15·19	S	4
9. vi	0400		23° 24′	71° 09′	27	15·6	SSW	5
	0500		23° 23′	71° 12′ 20″	31	17·59		
	0600					17·51		
	0900	629	23° 21′ 30″	71° 28′	46·5	18·04	SSW	5
	1200						S	5
	1600						S	4–5
	1815				? 44·5	17·9		
	1830					17·5		
	2007	630	23° 22′	71° 06′	25·5	17·31	S	3
	0000	630					S	2
10. vi	0400	630					Northerly	½
	0754	630	23° 13′ 30″	70° 56′	16·5			
	0838	631	23° 12′	70° 49′	11·5	16·5	NE	2
	1110	632	23° 10′	70° 46′ 30″	9	15·77	NE	2
	1325	633	23° 10′	70° 43′ 30″	6·5	15·85	N × W	2–3
	1523	634	23° 10′	70° 40′ 30″	4	15·11	N × W	3
	1658	635	23° 12′ 30″	70° 39′ 30″	2	14·9	N × W	4
	1900				3	15·0		
	1920					15·31		
	2000		23° 21′	70° 46′ 30″	8	16·61	Northerly	1–2
	2020				8	16·15		

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position		Distance offshore miles	Temp. °C.	Wind	
			Latitude S	Longitude W			Direction	Force
10. vi	2040					15·81		
	2050					15·63		
	2100					15·30		
	2110		23° 32′	70° 47′	7	15·31		
	2120					15·15		
	2125					14·95		
	2130				4·25	14·80		
	2135					14·60		
	2140					14·45		
	2145					14·35		
	2150					14·35		
	2200					14·14		
	2115					14·15		
	2225				3·5	13·98		
	2235					13·98		
	2250		23° 38′	70° 27′	1·5	13·9		
	2300		Antofagasta		0·3	14·68		
	0000						N. Easterly	2
11. vi	0400		Antofagasta				N. Easterly	2
	0800						N. Easterly	1–2
	1200						—	0
	1600						—	0
	2000						—	0
	0000						E	1
16. vi	0400		Antofagasta				E	1
	0645					14·8		
	0700				0·5	14·6		
	0715					14·64		
	0730				2·5	15·2		
	0745					15·35		
	0800		23° 35′	70° 39′	3·5	15·4	—	0–1
	0815					15·6		
	0830				4·25	16·6		
	0845				5·75	17·44		
	0900				7·0	17·59		
	0920					17·64		
	0940					17·69		
	1000				9·0	17·70		
	1030					17·70		
	1100				10	17·70		
	1140				10·5	17·2		
	1200		23° 06′	70° 45′	8·25	15·75	—	0–1
	1230					16·41		
	1300				8·5	16·19		
	1400				9·5	16·10		
	1500				5	16·06		
	1530				2–3	16·06		
	1600					15·7	Southerly	2
	1605					15·72		
	1610					15·71		

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position: Latitude S	Position: Longitude W	Distance offshore miles	Temp. ° C.	Wind: Direction	Wind: Force
16. vi	1615				1·5	15·82		
	1620					15·7		
	1625					15·65		
	1630		22° 37′	70° 20′	0·5	15·6		
	1635					15·57		
	1640					15·5		
	1645					15·65		
	1700				8	15·7		
	1730				9	15·95		
	1800				11	16·10		
	1900				14–15	16·62		
	2020	636	22° 04′ 30″	70° 36′	20	16·23	WSW	3
	0000				27	16·59	W	2
17. vi	0400				25	16·71	SW	2
	0815				10	17·63	NNE	2
	0900					17·2		
	1000				4	16·7		
	1030					16·5		
	1100					15·9		
	1130				0·5	15·52		
	1600		Iquique				WSW	3
	2000						—	0
	0000						—	0
18. vi	0400		Iquique				—	0
	0800						—	0
	1200						—	0
	1600						SW	1–2
	1800				4	16·3		
	1900				6	16·00		
	2008	637	19° 48′	70° 22′	9·5	15·67	NNW	2
	0000				18	18·59	SW	2
19. vi	0400				35	18·45	SW	2
	0520	638	18° 54′ 30″	71° 06′	41	18·62	SE	3–2
	0800						SE	3
	1230	639	18° 44′	70° 48′	23·5	18·62	SE	1–3
	1440				21·5	19·1		
	1600				14	18·7	—	1
	1630				8·5	18·1		
	1730				5	17·25		
	1745	640	18° 28′	70° 23′ 36″	3	16·57		
	1916	641	18° 27′ 30″	70° 26′ 30″	5	17·62	—	0–1
	2110	642	18° 28′ 24″	70° 32′ 12″	10	17·91		
	2324	643	18° 30′	70° 42′ 48″	17	18·12	WSW	2
20. vi	0400				18·5	17·66	WSW	2
	0800				8	15·92	Light airs	
	1200				5	16·1	Light airs	
	1300					16·45		
	1415				8	16·8		
	1430				6	16·35		

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position		Distance offshore miles	Temp. °C.	Wind	
			Latitude S	Longitude W			Direction	Force
20. vi	1440				4	15·9		
	1450		Mollendo		3	15·5		
	1530				3–4	16·22		
	1600				6	16·5	E	1–2
	1700					16·53		
	1715				10	17·10		
	1800				? 10	17·3		
	2010	644	16° 55′ 12″	72° 39′	? 15	16·43	Southerly	3
	0000				? 12	15·49	S. Easterly	
21. vi	0400				? 12	15·54	ENE	4–5
	0800				? 12	15·32	SSE	3–4
	1100				? 10	15·03		
	1200				? 7	15·21	NE	4
	1300				? 4	15·12		
	1400				? 1–2	14·79		
	1435				0·75	14·12		
	1500				1–2	14·45		
	1600				6	14·5	ESE	3–4
	2028	645	15° 42′ 18″	75° 03′	13·5	14·85	Southerly	3
	0000				22	15·03	Southerly	3
22. vi	0405	646	15° 35′	75° 41′	31	14·81	E×S	4
	0800						SE	4
	1155	647	15° 19′ 12″	75° 11′ 30″	1·25	13·79	SE	6–7
	1313	648	15° 19′ 30″	75° 13′	2	13·82	ESE	5
	1449	649	15° 20′	75° 16′ 30″	3·75	14·19	ESE	4–5
	1634	650	15° 22′ 30″	75° 22′	11·75	14·43	SE	3–4
	1930	651	15° 31′	75° 37′ 30″	22	14·86	SE	3–4
	0000				38	15·5	SE	4–5
23. vi	0100				45	15·68[1]		
	0200				54	16·21		
	0300				63	16·78		
	0400				72	16·85	SE	5–6
	0500				81	17·21		
	0600				90	17·82		
	0650	652	16° 21′ 30″	76° 30′ 12″	96	18·82	SE	5
	0800						SE	6
	1135					19·09		
	1200		16° 21′	76° 33′ 30″	100	19·25	SE	5–6
	1500				132	19·48		
	1600				141	19·40	SE	5
	1710	653	16° 54′	77° 13′	150	18·79	SE	5
	2000						SE	5
	0000						SE	4–5
24. vi	0015	654	16° 36′	76° 55′ 30″	124	19·22	ESE	4–5
	0400				120		SE×S	4–5
	0500				111	19·20		
	0600				102	18·78		
	0910	655	16° 08′	76° 22′	81·5	17·26	ESE	4
	1200						ESE	4

[1] The original log entry 15·18° C. appears to be a misreading.

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position Latitude S	Position Longitude W	Distance offshore miles	Temp. °C.	Wind Direction	Wind Force
24. vi	1405	656	15° 52′ 30″	76° 07′ 30″	62	16·24	SE	4
	1600						SE	4
	1900	657	15° 38′ 18″	75° 53′ 24″	42	15·36	SE	4
	2000						SSE	3
	0000				36	15·69	ESE	3
25. vi	0400				20	14·89	SE × S	4
	0500				16	15·24		
	0600					15·29		
	0800				8	15·38	SE	5
	1200						S	3
	1228	658	13° 45′ 30″	76° 20′	2·3	19·10	SW	4–5
	1240		Pisco					
	1600						SW	4–5
	2000						SSW	3
	2120	659	13° 37′ 48″	76° 20′	8·5	17·6	NW × N	3
	0000				12	16·59	NW × N	3
26. vi	0400				11·5	17·68	NNW	2
	0800				8–11	17·91	SSW	1
	0935	660	12° 23′ 30″	77° 11′ 12″	—	—	SW	2
	1200	661	12° 08′	77° 16′	6	16·61	SW	2
	1245	662	12° 09′ 30″	77° 15′	6	16·86	SW	2–3
	1600		Callao				Southerly	1–2
	2000						Southerly	1
	0000						Light airs	0
1. vii	0400		Callao				SE	1–2
	0800						—	0
	1000				0·5	16·8		
	1100				5·5	17·2		
	1140	663	12° 09′ 36″	77° 15′	6	17·21	ESE	1–2
	1325	664	12° 11′ 30″	77° 17′	9	17·21	SE	3
	1615	665	12° 13′ 18″	77° 21′ 48″	13·5	17·55	S	4
	1836	666	12° 18′ 30″	77° 30′ 30″		17·84	SE	3
	2030					18·4		
	2045					19·1		
	2055	667	12° 23′ 12″	77° 39′ 30″		19·13	SE	4
	0000						SSE	3
2. vii	0100				44	19·45		
	0300				62	19·1		
	0400				78	17·81	SSE	4–5
	0600				90	17·62		
	0700				99	18·39		
	0737	668	12° 48′ 30″	78° 45′ 48″	104	18·88	SE × E	4
	1200				102		SE × E	4
	1400				85	18·0		
	1455	669	12° 33′ 30″	78° 21′ 36″	77	17·22	SE	5
	1600						SE	4–5
	2012	670	12° 22′ 12″	78° 13′ 48″	64	19·21	SE	4
	0000	671	12° 10′ 48″	77° 59′ 12″	48·5	19·33	SE	4
3. vii	0400						SE	5

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position: Latitude S	Position: Longitude W	Distance offshore miles	Temp. °C.	Wind: Direction	Wind: Force
3. vii	0800					17·33	SE	4–5
	1200		Callao				—	0
	1600						Southerly	1–2
	2000						Southerly	2–3
	0000						SE	1–2
8. vii	0400		Callao				—	0
	0700				4	16·65		
	0715				6	16·9		
	0730				6	17·35		
	0805	672	12° 09′ 42″	77° 14′	6	17·33	SSE	3
	0930				4	17·1		
	1200		Callao				SE	1–2
	1600						SSE	3
	1645				5·5	16·85		
	2012	673	11° 23′ 36″	77° 38′	9	17·32	SSE	3
	0000				12	18·85	Southerly	1–2
9. vii	0400				20	19·69	Southerly	2–3
	0800				26	19·50	ESE	3
	1200		9° 45′ 30″	78° 55′	39	20·6	ESE	3
	1600					20·58	S	3
	1800				51	20·59		
	1915	674	9° 00′	79° 40′	56	20·36	ESE	3
	2215				50·5	19·5		
	2300				47	19·38		
	0000				40	17·22	E	2–3
10. vii	0100					17·75		
	0200					17·6		
	0300					17·28		
	0400				16·5	17·09	E	2
	0500				10	16·72		
	0600					16·50		
	0700					16·27		
	0800					16·35	E	1–2
	0830		Salaverry		1·75	16·35		
	1200						SW	1
	1305	675	8° 14′ 30″	78° 58′	1·75	16·00	SW	1
	1413	676	8° 17′	79° 01′ 30″	5	16·71	SSW	2
	1525	677	8° 19′ 30″	79° 05′ 45″	9·5	16·82	SSW	2
	1600						SSW	1–2
	1700				8	17·99		
	1745				6·5	17·8		
	1824	678	8° 35′ 30″	78° 57′	8	16·85	SW	1
	2000	679	8° 38′	79° 01′ 30″	12·5	17·39	SSW	2
	2145					17·5		
	2200					17·4		
	2238	680	8° 44′	79° 15′	26·5	17·4	SW	1
11. vii	0100	681	8° 49′	79° 24′	36·5	19·44	SE	2
	0320	682	8° 53′	79° 33′	46·5	20·04	SE	2
	0400						Southerly	1

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position: Latitude S	Position: Longitude W	Distance offshore miles	Temp. ° C.	Wind: Direction	Wind: Force
11. vii	0800						SSE	3
	1200		9° 37′		36	20·25	SSE	3
	1600		10° 07′		29	20·23	S × E	3
	2000	683	10° 37′	78° 17′ 15″	24	20·18	SE × S	3–4
	0000				17	20·23	SE	3
12. vii	0400						SE	3–4
	0800				17	18·4	SSE	3
	1015	684	12° 09′ 30″	77° 15′	6	17·26	SSE	3
	1200		Callao				S	1–2
	1600						S	1–2
	2000						S	1–3
	0000						SE	2
15. vii	0400		Callao				Southerly	1–2
	0800						Southerly	2
	1200						—	0
	1600						SW	2
	1716	685	12° 09′ 30″	77° 15′	6	17·12	S × E	3
	2000				11·5	18·3	SW × W	1–2
	2100				19	17·71		
	0000				26·5	17·53	SSW	0
16. vii	0100				25	19·91		
	0200				30	20·02		
	0300				34	20·02		
	0400				40	19·9	SW	2
	0500				45	20·23		
	0800				55	20·05	SSW	3
	1200		10° 32′	79° 12′	68	20·08	SSW	2–3
	1300				75	19·86		
	1600				80	19·82	SSW	2–3
	1800		? 10° 00′		87	20·42		
	2000		09° 49′		93	20·20	SSW	3–4
	0000					20·20	SE	2–3
17. vii	0036	686	09° 25′ 30″	80° 22′	104·5	20·24	SE	4–5
	0400						SE	5
	0800				104	20·8	SE	5
	1200		? 08° 39′		97	19·6	SSE	4
	1300					19·2		
	1400		? 08° 27′		100	18·87		
	1500					18·78		
	1600				97	19·01	S	3
	1800					18·9		
	1900		? 07° 58′			19·00		
	2000					19·10	S	4
	2100				104	19·8		
	2220	687	07° 42′	82° 09′	116	19·64	SE	4–5
	0000						SE	4–5
18. vii	0400						SE	3–4
	0800						SSE	3–4
	1156	688	07° 19′	81° 35′	78	18·65	SSE	2–3

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position		Distance offshore miles	Temp. ° C.	Wind	
			Latitude S	Longitude W			Direction	Force
18. vii	1600					19·00	SSE	2–3
	1920	689	07° 01′	81° 09′	51	18·55	SSE	3
	0000						SSE	2–3
19. vii	0230	690	07° 03′	80° 40′ 36″	40	18·14	SSE	3–4
	0400					18·26	Southerly	2
	0600	691	06° 59′ 45″	80° 15′	24	17·38	SE	2–3
	0800						S × W	3
	1020	692	06° 29′ 15″	80° 33′	6	17·4	S	1–3
	1200					17·4	SE	3
	1310	693	06° 35′ 12″	80° 40′	14	17·84	SSE	3
	1435				18	18·10		
	1508	694	06° 38′	80° 49′ 54″	21·5	18·15	SSE	3
	2100	695	06° 48′ 12″	80° 55′	32·5	18·14	SSE	2
	0000						SE	3
20. vii	0030	696	06° 54′ 48″	81° 02′	42	18·23	SSE	3
	0400						SSE	2
	0800		Lobos de Tierra				—	0
	1200						SE	1
	1600						SE	2–3
	2000						SSE	3
	0000				10	18·03	—	0
21. vii	0400		Lobos de Tierra				—	0
	0500				10	17·89		
	0600				10	17·69		
	0700				7	17·62		
	0800				4·75		—	1–2
	0930				1·5	17·2		
	1000				1·5	17·15		
	1025	697	05° 55′ 30″	81° 09′	1·25	16·50	SSW	3–4
	1142	698	05° 55′	81° 09′ 45″	2·25	16·60	S × W	5
	1255	699	05° 54′	81° 11′ 42″	4·5	17·79	S × W	4
	1432	700	05° 52′	81° 15′ 30″	8·5	18·26	S × E	5
	1700	701	05° 48′	81° 22′ 30″	17	18·49	S	3–4
	2000						S	3–4
	2225	702	05° 38′	81° 40′	37	18·33	S	3–4
	0000						S	3
22. vii	0300					18·25	S	3
	0330					18·27		
	0400					18·3	SW	2
	0430					18·3		
	0500					18·21		
	0530					18·27		
	0600					18·24		
	0700	703	05° 34′	82° 11′ 30″	68	18·18	SE	2–3
	0800						SE	2–3
	1200						SSE	1–2
	1600					18·80	SW	2

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position: Latitude S	Position: Longitude W	Distance offshore miles	Temp. °C.	Wind: Direction	Wind: Force
22. vii	1700	704	05° 33′	82° 47′	103	18·64	SE	2
	2000						SSE	1
	2130					18·41		
	2200					18·5		
	2230					18·42		
	2300					18·61		
	2330					18·59		
	0000					18·54	SW	1–2
23. vii	0030					18·27		
	0100					18·39		
	0130					18·48		
	0200					18·95		
	0230	705	05° 35′ 30″	83° 41′ 45″	157	19·03	SSW	1–2
	0400						SSW	1–2
	0800						E × S	1
	0955	706	05° 37′ 30″	83° 58′	174	19·74	ESE	2–3
	1200						ESE	2
	1530	707	05° 37′ 30″	84° 31′ 30″	207	20·69	SE	3
	1600						SE	2
	2000				190	20·2	SE	3
	0000				163	20·00	NE	4–5
24. vii	0200				146	19·6		
	0400						SE × E	2
	0430				135	19·00		
	0530				128	18·55		
	0630				? 133	19·21		
	0755					19·48	SE	3
	0900				? 145	19·79		
	0930				154	20·09		
	1008				166	20·00		
	1130				? 154	19·70		
	1200		04° 17′ 30″	83° 27′	150–130	19·65	SE	3
	1315				? 144	19·18		
	1400				? 135	18·82		
	1600				? 121	18·95	SE × E	3–4
	2030				? 65	18·89	ESE	3
	2130				? 57	19·00		
	2200				? 50	19·00		
	2245	708	04° 18′	82° 05′	47	18·52	SSE	2
	0000						SSE	2
25. vii	0400						SSE	3–4
	0430				43	17·9		
	0600				33	17·0		
	0630					16·83		
	0700					16·9		
	0730				22	17·06		
	0800					17·09	SSE	3–4
	0830				15	18·21		
	0900				11	20·34		
	0935				8	21·34		

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position: Latitude S	Position: Longitude W	Distance offshore miles	Temp. °C.	Wind: Direction	Wind: Force
25. vii	1000				4	21·48		
	1030				1	22·40		
	1040	709	04° 17′	81° 16′ 45″	0·5	22·63	SSW	5
	1220	710	04° 18′	81° 20′ 15″	4	21·54	S	5
	1352	711	04° 19′ 30″	81° 27′	11	21·19	S	5–6
	1600						S	5–6
	1845	712	04° 20′	81° 37′ 45″	19·5	20·44	S	4–5
	2000						S	5–6
	2155	713	04° 20′	81° 47′	31	16·84	SSE	3–4
26. vii	0100	714	04° 20′	81° 57′ 30″	40	17·00	S × E	4
	0330				38	17·00		
	0400					16·91	S	4
	0430				35	16·83		
	0500				32	17·68		
	0530				28	18·92		
	0600				24	19·15		
	0730				14·5	19·48		
	0800				11·5	17·7	S	4
	0930				2	17·3		
	0937				1	16·8		
	0945		Talara		0·25	16·8		
	1200						S	4
	1600						S	4
	2000						S	4
	0000						S	5
30. vii	0400		Talara				Southerly	2–3
	0800						SSE	1–3
	1200						Southerly	3
	1600						SW	4
	1625				0·5	16·8		
	1730				8	17·97		
	1800				11·5	18·9		
	1830				15	19·9		
	1930				23	20·18		
	2000				27	20·00	SW	4
	2030				32	19·47		
	2200				44	19·2		
	2230		04° 17′	82° 05′	48	18·39		
	2300				48	19·02		
	0000						Southerly	3–4
31. vii	0030				48	19·85		
	0100				49	20·15		
	0130				49	20·7		
	0200				50	21·1		
	0400				58	21·17	S	3
	0800				61	21·93	SSW	4
	0830				58	22·8		
	0900				53	23·1		
	1000				39	23·55		
	1200				35·5	23·87	SSW	3

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position: Latitude S	Position: Longitude W	Distance offshore miles	Temp. ° C.	Wind: Direction	Wind: Force
31. vii	1230				31	23·9		
	1300		02° 16′	81° 29′	29	24·1		
	1500				13·5	24·4		
	1600	715	02° 11′ 15″	81° 04′	3	24·3	S	3
	1720	716	02° 11′	81° 09′	8	24·43	S	3
	1920	717	02° 12′	81° 18′ 30″	18	24·22	SSW	3
1. viii	0025	718	02° 11′	81° 33′ 30″	33	23·85	SW × S	3
	0440	719	02° 11′	81° 53′	53	22·99	SSW	2
	0800						SSW	2–3
	1200		02° 25′	81° 49′	57		Southerly	4–5
	1230					22·78		
	1430				66	22·40		
	1530				74	21·7		
	1640				84	21·00	Southerly	5–6
	1730	720	02° 52′ 15″	82° 19′ 30″	91	21·06	S	4
	2000				95	20·7	S	4–5
	2100				101	20·2		
	2300				105	19·95		
	0000				107	19·79	S	5–6
2. viii	0125	721	03° 29′	82° 51′	108	19·15	S × W	4
	0400					19·05	S × W	4
	0500					18·69		
	0800						SE	3–4
	1030	722	04° 20′ 24″	83° 03′	107	18·55	SE	3–4
	1200						SE	3–4
	1600						S	4
	2000					18·40	SE	4–5
	2130	723	05° 01′ 30″	83° 49′	155	18·44	SE	4–5
	0000				159	18·87	SE	4
3. viii	0300				176	18·97		
	0400				185	19·49	S × E	5
	0500				190	20·00		
	0630	724	05° 35′ 42″	84° 33′	203	20·06	SSE	4–5
	0800						S × E	5
	1200				227	20·30	SSE	4
	1430	725	06° 25′	85° 04′ 12″	241	20·13	SE	5–6
	1600						SE	5–6
	1700					19·90		
	1800					19·20		
	2000					19·15	SSE	5–6
	2100				247	19·58		
	2200				249	20·01		
	2300				253	19·62		
	0000					20·5	SSE	6–7
4. viii	0015	726	07° 20′	85° 12′ 30″	257	20·02	SE	6
	0400						SE	5–6
	0800						ESE	5
	0920					19·6		
	1200		07° 45′	84° 30′	221		SE	4

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position Latitude S	Position Longitude W	Distance offshore miles	Temp. ° C.	Wind Direction	Wind Force
4. viii	1230					19·30		
	1600						SE	5
	2000						SE	5–6
	2130					19·70		
	0000				199	20·08	SE	6
5. viii	0400				190	18·89	SE	5–6
	0800					18·40	SE × E	5
	1200		09° 12′ 30″	82° 00′ 15″	182	17·90	SE × E	5
	1600				163	18·4	SE	5
	2000				151	19·00	SE × S	5
	0000				130	18·48	SE	5
6. viii	0400				117	18·65	SE	5
	0800				96	18·72	SE	4–5
	1200		10° 37′	79° 15′ 30″	73	18·62	SE	4
	1600				57	18·3	SE	5
	2000				45	16·4	SE × S	4
	0000						SE	4
7. viii	0400				21	16·48	SE × S	3
	0730	727	12° 09′ 30″	77° 15′	6	14·88	SSE	3
	1200		Callao				WSW	1–3
	1600						SW	2
	2000						—	0
	0000						—	0
20. viii	0400		Callao				—	0
	0806	728	12° 09′ 30″	77° 15′	6	15·73	S. Westerly	2
	0948	729	12° 11′ 30″	77° 20′	11·5	16·64	S. Westerly	2
	1204	730	12° 15′	77° 27′	19	17·58	SSW	2
	1502	731	12° 22′	77° 40′	34	17·73	SSE	2
	1900				52	17·50		
	2021	732	12° 36′	78° 07′	65	16·51	Southerly	2–3
	0000				72	16·63	Southerly	2
21. viii	0230				88	15·97		
	0300				91	15·93		
	0330				94	16·08		
	0400				98	16·03	Southerly	2
	0515	733	12° 54′ 30″	78° 43′	105	15·91	SE	3
	0800				114	17·62	S	2
	1250	734	13° 16′ 30″	79° 27′ 30″	154	17·16	Southerly	3
	1600						SSE	2–3
	2000					17·15	SE	3
	2200					17·69		
	0000					17·13	SE	3
22. viii	0200					16·7		
	0400					17·55	SSE	3–4
	0800					17·5	SE	4
	1200				153	17·51	SE	4
	1600					17·59	SE	4
	1800					16·43		

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position: Latitude S	Position: Longitude W	Distance offshore miles	Temp. °C.	Wind: Direction	Wind: Force
22. viii	2000					16·67	SE	4–5
	0000				177	16·70	SE	5
23. viii	0400				192	16·47	SE × S	4
	0845	735	17° 47′	77° 36′	204	16·71	SE	4
	1200				210	17·6	SE	4
	1600				235	17·72	SE	4
	2030					17·51	SE	4
	0000				260	17·69	SE	4
24. viii	0200					17·8		
	0400				275	16·85	SE	4
	0800				294	16·67	SE	4
	1000				305	16·87		
	1200					16·98	SE	4
	1600				331	17·10	SE × S	4
	1800				327	16·67		
	2000				314	16·67	S	4
	0000				295	16·68	S	4
25. viii	0450	736	22° 37′ 18″	75° 27′	275	16·35	S × E	4
	0800						SSE	3
	1200				263	16·49	SSE	3
	1600					15·93	S	4
	2000				245	15·93	SSE	4–5
	0000				233	15·41	SSE	4–5
26. viii	0400					15·3	SSE	4–5
	0800				202	15·53	SSE	4
	1200					15·89	SSE	4
	1600				175	15·42	S × E	4
	1800					15·37		
	2000				159	14·77	S × W	4–5
	2200					15·24		
	0000					14·90	S	5–6
27. viii	0107	737	27° 23′	73° 40′	136	14·58	SSE	5
	0400					15·00	S × E	4–5
	0600					14·95		
	0820					14·49	S × E	4
	1000				98	13·93		
	1200					13·82	S × E	4
	1600					13·9	Southerly	4
	2000				69	13·55	SW × S	4
	0000				45	13·84	SSW	4–5
28. viii	0400				35	13·55	S × W	3–4
	0600					13·90		
	0800				32	12·28	S × W	3
	1000					13·20		
	1200		31° 19′	72° 12	23	13·40	S × W	3
	1600				14	13·45	S × W	4–5
	1800				8·5	12·97		
	1930	738	32° 04′ 30″	71° 36′	0·3	12·1	S	6

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position		Distance offshore miles	Temp. °C.	Wind	
			Latitude S	Longitude W			Direction	Force
28. viii	2208	739	32° 05′	71° 47′ 30″	9·0	12·81	S	6
	0000						S	6
29. viii	0400				? 16	12·96	S	6–7
	0800						S	6–7
	1200						S × W	4–5
	1600		Valparaiso				SSE	1
	2000						SE × E	1
	0000						Light airs	0
3. ix	0400		Valparaiso				E × N	1–3
	0800						E × N	1–2
	1200						Southerly	3
	1600						SSW	4
	2000	740	33° 56′	72° 15′	18	12·08	SW × S	4
	0000				18	12·63	S × W	4
4. ix	0400				22	12·52	SSW	4
	0800				23	12·51	S	4
	1200		35° 15′ 30″	73° 08′ 30″	23	12·13	SSW	4
	1600				21	12·04	SSW	4–5
	2000	741	36° 00′	73° 15′ 30″	25	11·95	SW	4
	0000				20	11·65	Southerly	3
5. ix	0400				15	11·85	SSW	3
	0800				4	11·20	—	0
	1200		37° 43′	73° 45′	6	11·14	—	0
	1600				12–15	11·21	W	2
	2000	742	38° 22′	73° 41′	7–10	11·27	NNW	2
	0000				15	10·95	WNW	1–2
6. ix	0400				23	11·05	W × S	2–3
	0800				6–7	10·54	Westerly	2–3
	1200		Corral				NNW	4
	1600						NW	1
	2000						NW	1–2
	0000						N	1
8. ix	0400		Corral				ENE	1–2
	0800						SE	3–4
	1200		40° 03′ 30″	73° 49′	5	10·13	Southerly	4
	1600				8	10·05	Southerly	4
	2000	743	41° 05′	74° 05′	7	9·9	SSW	3
	0000				16–17	10·16	S. Easterly	3–5
9. ix	0400				18	9·90	SE	4–5
	0800				24	9·75	SE	4
	1200		42° 56′ 30″	74° 49′	? 29	9·58	SE	4–5
	1600				? 35	9·42	SE	5
	2000	744	43° 40′ 30″	75° 07′ 30″	? 43	9·34	SE	5
	0000				? 40	9·15	SE	5
10. ix	0400				? 38	8·84	SE × E	5–6
	0800				? 44	7·70	SE × E	5
	1200		45° 29′	75° 08′	? 24	8·67	Easterly	5

APPENDIX IV (*cont.*)

Date 1931	Hour	Station WS	Position		Distance offshore miles	Temp. ° C.	Wind	
			Latitude S	Longitude W			Direction	Force
10.ix	1600				? 19	8·75	Variable	2
	2000	745	46° 41′	75° 45′	? 4	8·45	SSE	3
	0000				7	8·25	SE × S	2
11.ix	0400				9	7·91	—	1
	0800		Patagonian Channels		0·5–2·0	6·12	SE	2
	1200						SE	2

APPENDIX V

Mean wind vectors (plotted in Fig. 4)

Latitude ° S	Date	R.R.S. 'William Scoresby'						Chilean Meteorological Stations			
		Zone > 50 m. offshore			Zone < 50 m. offshore			Mean of observations within a period of 14 days prior to ship's reaching same latitude			
		No. of obs.	Mean vector		No. of obs.	Mean vector		Position of station	No. of obs.	Mean vector	
			Direction	m.p.h.		Direction	m.p.h.			Direction	m.p.h.
46–48	10. v. 31				3	S 20° E	6·33				
44–46		2	S 30° E	11	1	S 22·5 E	21	Aysen	8	SW 2	0·25
42–44	11. v. 31	3	S 77° E	14	1	E	15	Huafo	11	S 21° W	7·2
40–42	12. v. 31				3	S 68° E	18·7				
38–40	12–15. v. 31				18	S 67° E	5·8	Corral	15	S 82° E	3
								Mocha I.	16	S 7° W	10
36–38	15–18. v. 31				14	S 12° E	0·5	Lebu	12	S	17·5
								Talcahuano	17	S 45° E	3·6
34–36	18–20. v. 31	6	S 38° E	5·83	22	N 28° E	4·4	Constitution	14	N 55° E	1·8
32–34	21–28. v. 31				49	S 46° E	1·3	Valparaiso	21	S 20° E	0·38
	29. v. 31	6	S 2° E	12·1							
30–32		4	S 2° E	24·25							
	30–31. v. 31				4	S	7·5				
28–30	31. v. 31				23	N 62° W	1·3	Coquimbo	14	N 57° E	1
	4. vi. 31										
26–28	4–7. vi. 31	4	S 3° W	6·5	16	N 39° E	0·69	Caldera	15	S 80° E	2·26
24–26					4	S 4° E	11·5	Taltal	14	N 45° E	0·64
22–24	8–9. vi. 31				14	S 4° E	12·7				
	10. vi. 31				7	N 1° E	6·1				
	10–16. vi. 31				36*	N 47° W	0·72	Antofagasta	21	S 73° E	1·8
20–22	17–18. vi. 31				10	S 74° W	1·8	Iquique	14	S 71° W	1·5
18–20	18–20. vi. 31				10	S 5° W	2·3	Arica	17	N 89° E	1
16–18	20–21. vi. 31				6	S 81° E	6·17				
	23–24. vi. 31	11	S 47° E	20·5							
14–16	24. vi. 31	3	S 53° E	14·7	16	S 48° E	14·5				
12–14	25–26. vi. 31				10	S 57° W	6·2				
	26. vi. 31				30†	S 9° E	3·7				
	1. vii. 31										
	1–3. vii. 31	6	S 44° E	16·7	8	S 37° E	13·7				
	3–8. vii. 31				30	S 20° E	2·2				
	12. vii. 31				1‡	S 23° E	10				
	12–15. vii. 31				21†	S 11° E	3·05				
10–12	8–9. vii. 31				6	S 28° E	6·6				
	11–12. vii. 31				6	S 31° E	10·5				
	15–16. vii. 31	3	S 23° W	8·3	2	S 50° W	4				
8–10	9–11. vii. 31	2	S 35° E	8·5	16	S 35° E	3·1				
	16–17. vii. 31	7	S 30° E	13·3							
6–8	17–21. vii. 31	8	S 31° E	12·13	20	S 25° E	6·1				
4–6	21–31. vii. 31	20	S 49° E	6·1	25	S 1° W	14·4				
					26§	S 15° E	11·9				
	2–3. viii. 31	10	S 28° E	15·3							
2–4	31. vii. 31	11	S 6° W	14·9	5	S 16° W	9·6				
	2. viii. 31										
6–8	3–4. viii. 31	8	S 39° E	23·4							
8–10	4–5. viii. 31	8	S 48° E	21·6							
10–12	5–7. viii. 31	6	S 43° E	19	3	S 38° E	13·3				
12–14	7–20. viii. 31				77†	S 9° E	1·7				
	20–21. viii. 31	9	S 23° E	7·2	4	S 24° W	4·5				
14–16	22. viii. 31	4	S 41° E	14							
16–18	22–23. viii. 31	5	S 42° E	17							
18–20	23–24. viii. 31	4	S 45° E	15				Arica	7	E	0·57
20–22	24. viii. 31	5	S 25° E	14				Iquique	16	S 50° W	0·5

APPENDIX V (*cont.*)

Latitude °S	Date	R.R.S. 'William Scoresby'						Chilean Meteorological Stations			
		Zone > 50 m. offshore			Zone > 50 m. offshore			Mean of observations within a period of 14 days prior to ship's reaching same latitude			
		No. of obs.	Mean vector		No. of obs.	Mean vector		Position of station	No. of obs.	Mean vector	
			Direction	m.p.h.		Direction	m.p.h.			Direction	m.p.h.
22–24	25. viii. 31	5	S 15° E	13·4				Antofagasta	16	S 50° E	2·7
24–26	25–26. viii. 31	4	S 23° E	22				Taltal	15	N 60° E	2·3
26–28	26–27. viii. 31	6	S 8° E	18·1				Caldera	15	N 72° E	2·2
28–30	27. viii. 31	3	S 8° W	14·1	1	S 23° W	18	Coquimbo	17	N 75° E	0·5
30–32	28. viii. 31				4	S 11° W	12·5				
32–34	28. viii. 31				7	S 4° W	24·7				
	3. ix. 31										
					31‖	S 28° E	0·7	Valparaiso	20	S 82° E	0·7
34–36	3–4. ix. 31				5	S 16° W	15·4	Constitution	7	S 45° W	1·7
36–38	4–5. ix. 31				6	S 33° W	5·8	Lebu	10	S 8° E	7·5
								Talcahuano	16	S 4° W	3·0
38–40	5–8. ix. 31				16	N 39° W	2	Mocha I.	14	S 25° W	7·6
								Corral	1	W	5
40–42	8–9. ix. 31				5	S 17° E	13				
42–44	9. ix. 31				5	S 45° E	19·2	Huafo I.	11	S 87° W	3·3
44–46	10. ix. 31				3	S 67° W	21·3	Aysen	5	N 45° W	0·6
46–48	10–11. ix. 31				2	S 26° E	7·0				

* Antofagasta Harbour. † Callao. ‡ Callao, WS 684. § Talara. ‖ Valparaiso.

The original observations made on board R.R.S. 'William Scoresby' are given in Appendix IV. Those of the Chilean stations are published in the Santiago de Chile Daily Weather Reports.

APPENDIX VI

Mean surface temperatures (plotted in Fig. 34)

Date 1931	Lat. ° S	Mean surface temperature at different distances from the coast*													
		0–2 miles		2·1–5 miles		5·1–10 miles		10·1–20 miles		20·1–50 miles		50·1–100 miles		100·1–200 miles	
		No. of obs.	Mean temp. ° C.	No. of obs.	Mean temp. ° C.	No. of obs.	Mean temp. ° C.	No. of obs.	Mean temp. ° C.	No. of obs.	Mean temp. ° C.	No. of obs.	Mean temp. ° C.	No. of obs.	Mean temp. ° C.
10. v.	46									1	11·7				
11. v	44											1	12·0		
11. v	42											1	12·73		
12. v	41							1	12·66						
15. v	39	1	9·8					1	11·22						
	38							1	11·19	1	10·67				
	37							1	12·18						
16. v	36							2	11·45						
18. v	35			3	11·54	2	11·84	1	11·62	4	12·3	2	13·61		
20. v	34							2	12·63						
21. v	33							1	12·81						
28. v	32	1	14·02†			2	13·91	2	13·95	3	14·07†‡	6	14·91†‡	10	16·15
30. v	31							1	13·89	1	14	4	14·35		
31. v	30			1	13·05			1	15·75						
31. v–3. vi	29	2	14·25	2	14·53	2	14·29	3	14·33						
3. vi	28							1	15·2	1	14·41				
4–5. vi	27	2	13·27	1	14·20	1	14·88	2	15·5	3	16·51	1	16·61		
6–7. vi	26					1	15·70			2	16·36				
7. vi	25			7	14·46	19	16								
7. vi	24	5	16·43	8	16·29										
7–16. vi	23	8	14·47	19	14·82	20	16·26	4	15·97	8	17·26				
16. vi	22	7	15·68	5	15·79	4	15·98	3	16·32						
16. vi	21									2	16·65				
17. vi	20	1	15·52	3	16·4	2	17·41								
18. vi	19			1	16·3	2	15·83	1	18·59	1	18·45				
19. vi	18			3	17·15	2	18	3	18·16	3	18·78				
20. vi	17			4	15·93	8	16·62								
20. vi	16	1	14·79	1	15·12	2	15·12	4	15·69						
21–23. vi	15–16	4	14·04	1	14·19	1	14·5	1	14·43	8	15·22	9	17·39	6	19·14
25. vi	14					1	15·38	3	15·14						
25. vi	13			1	19·1	1	17·6	1	16·59						
26. vi–15. vii	12	1	16·8	1	16·65	13	17·15	2	17·62	6	18·87	6	18·16	1	18·39
8–15. vii	11					1	17·32	5	18·69	6	19·6				
9–16. vii	10							1	19·69	3	19·97	5	20·04		
9–17. vii	9									3	20·47	2	20·28	2	20·52
9–17. vii	8	2	16·35	2	16·13	7	17·05	4	17·34	8	18·26§	7	19·12		
17–18. vii	7									2	18·20	3	18·73	4	19·38
19–20. vii	6					5	17·74	3	17·78	4	17·97				
21. vii–2. viii	5	3	16·95	2	17·19	1	18·26	1	18·49	5	18·29	4	18·22	20	18·92
24. vii–2. viii	4	2‖	22·51‖	2‖	21·49‖	1‖	21·34‖	9	19·25	22	18·03	2	18·94	15	19·28
31. vii–2. viii	3									2	20·42	2	21·14	5	19·63
31. vii–1. viii	2			1	24·3	1	24·43	2	24·31	6	23·85	10	22·03		

* Mean temperatures in the 200–500 mile zone:

23. vii–2. viii 5° S (2 obs.) 20·38° C.
3. viii 6° S (5 obs.) 19·73° C.
3. viii 7° S (6 obs.) 19·89° C.

† These data have not been plotted in Fig. 34. ‡ Include observations not given in Appendix IV.

§ This datum has been erroneously plotted in Fig. 34 as 16·77.

‖ These data do not include observations off Talara: they are based on observations off Capo Blanco only, and represent temperatures in the tongue of the Equatorial Counter-current.

Note. The time interval between observations that have been averaged, does not exceed 20 days.

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PLATE XIV

Photographs illustrating scenery and climate in South America.

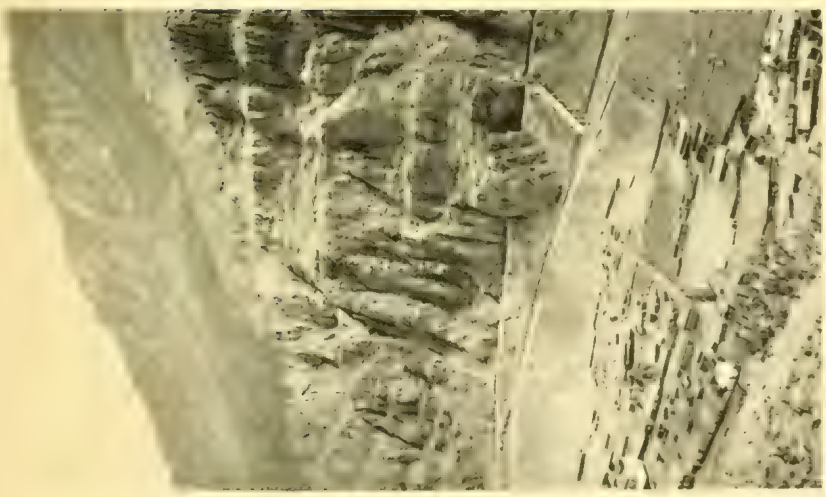
Figs. 1 and 2, taken in lat. 10–12° S, and Figs. 3 and 4, taken in lat. 49–53° S, illustrate the reversed character of the scenery west and east of the Cordillera. Figs. 1 and 3 of the west coast fall respectively within the South Pacific high pressure area and the region of the westerly winds, and correspond to the tracts of the Peru Current and the Cape Horn Current.

Fig. 1. Chicla in the Peruvian Sierra (lat. 10–12° S). 10. viii. 31.

Fig. 2. The Peruvian Montaña near San Ramón (lat. 10–12° S) showing forests of the Amazon basin.

Fig. 3. Field Anchorage, Straits of Magellan (lat. 53° S). 15. ix. 31.

Fig. 4. Monte Kochaik, Argentina (lat. 49° S). 19. ii. 03.



1

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4

H L Crosthwait lith

TYPES OF SOUTH AMERICAN SCENERY AND CLIMATE

PLATE XV

Fig. 1. Cormorants (*Phalacrocorax bougainvillii*), locally known as Guanay; in Callao harbour. 16. viii. 31.

Fig. 2. Cormorants in foreground and pelicans (*Pelecanus thagus*), locally known as Alcatraz; at Antofagasta. 13. vi. 31.

Fig. 3. Gannets (*Sula nebouxi* and *S. variegata*) known locally by the name of Camanay and Piquero; on Lobos de Tierra. 20. vii. 31.

Fig. 4. Widespread mortality of the squid *Dosidicus gigas* in Talcahuano harbour. 15. iv. 30.

E R G phot

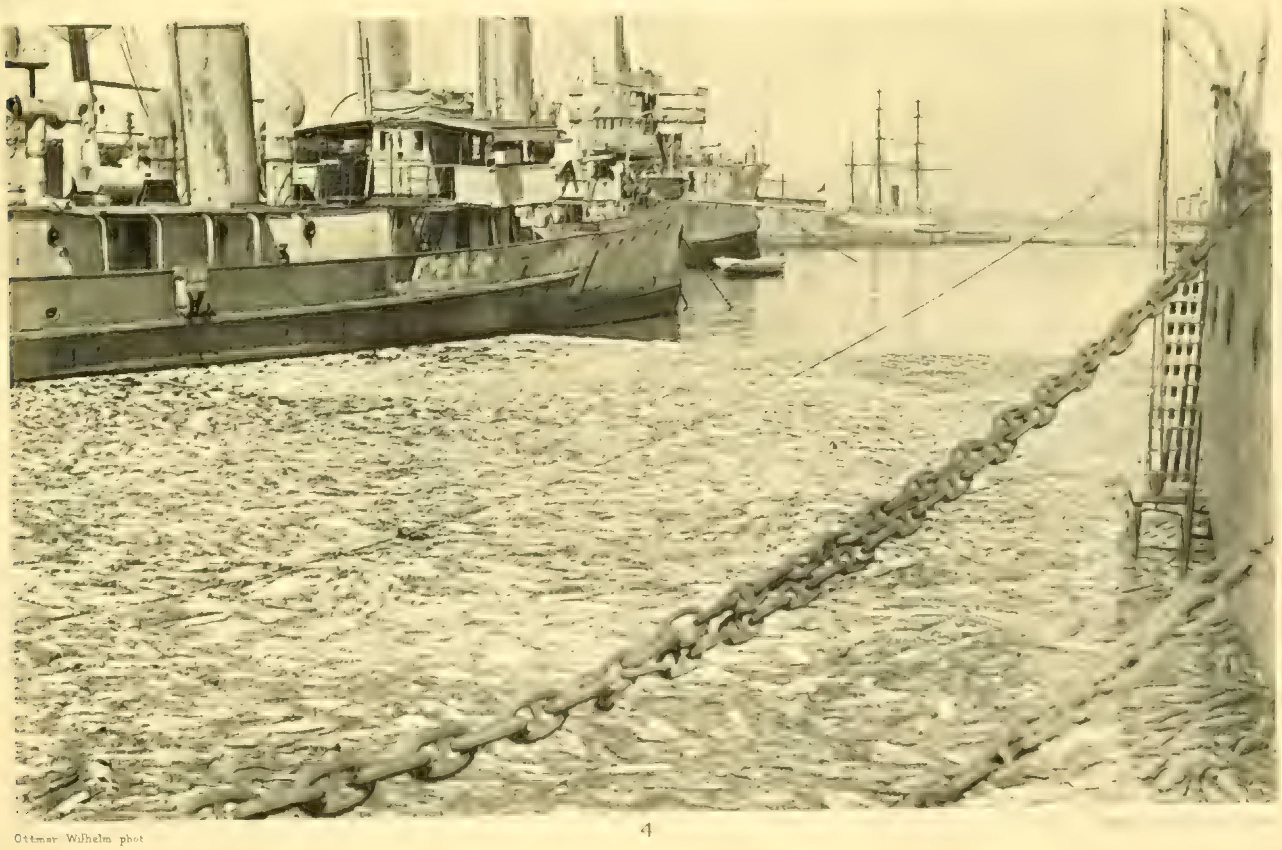
1

F. L. phot

2

E R G phot

3



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4

GUANO BIRDS AND SQUIDS OF THE PERU COASTAL CURRENT

PLATE XVI

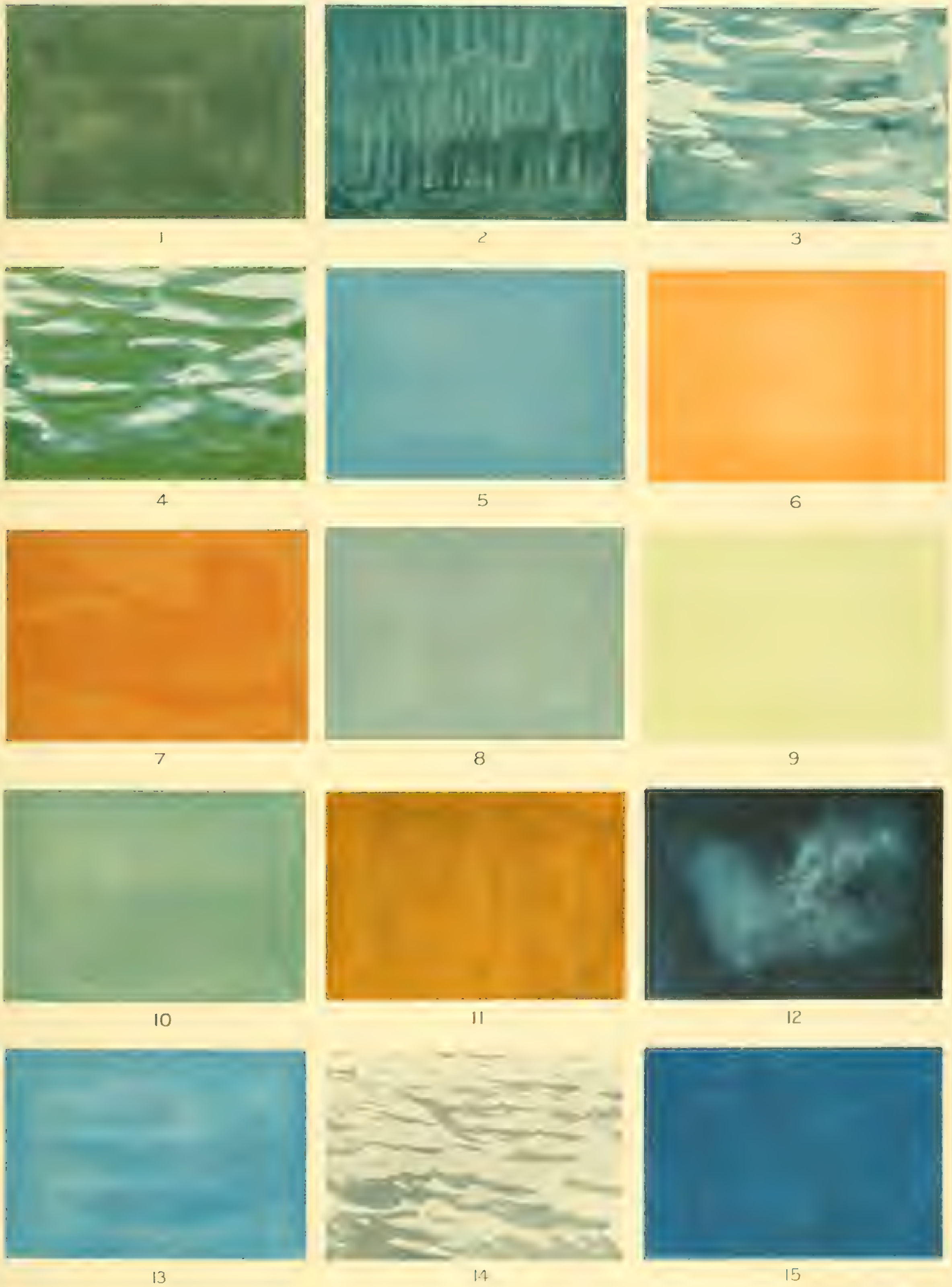
Coloured figures illustrating the appearance of the sea, executed by the author during the survey.

The blue washes in Figs. 5, 13 and 15 illustrate the appearance of the open ocean in sunny conditions, the indigo, Figs. 12 and 14 when overcast: these sketches were made at more than 30 miles from the coast (see below). The green washes, Figs. 1, 4, 9 and 10 may be looked upon as normal for the in-shore water: Figs. 2, 3 and 8 as intermediate between the blue and green. The reddish yellow Figs. 6, 7 and 11 found respectively at Pisco, Callao and the Guañape Islands are abnormal colorations (see pp. 221–2).

The colours (Figs. 3, 4 and 14 excepted) represent transmitted light and were obtained by looking down into the water under the overhang of the ship's stern where interference from reflected light is mostly eliminated. In Fig. 12 a swirl of air bubbles produced by the screw is indicated. The importance of avoiding sky reflections is shown in Fig. 4 in which surface reflection was blue but the colour of the water in wave shadows was green: compare also Figs. 2 and 12 with the corresponding appearance of the sea surface in Figs. 3 and 14.

A Table showing date, hour, position and nomenclature of the original observations illustrated in Plate XVI is given in Appendix III.

Fig.	Locality	Miles from land	Fig.	Locality	Miles from land
1	44° S	63	9	Salaverry	10
2	25° S	10	10	Salaverry	9
3	25° S	10	11	Guañape Islands	8
4	Antofagasta	1	12	10° S	63
5	Antofagasta	46	13	23° S	255
6	Pisco	2	14	10° S	63
7	Callao	6–15	15	31° S	32
8	Callao	6			



COLORATION OF SEA WATER IN THE PERU CURRENT

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RHINCALANUS GIGAS (BRADY) A COPEPOD OF THE SOUTHERN MACROPLANKTON

by

F. D. Ommanney, Ph.D. (Lond.), A.R.C.S.

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RHINCALANUS GIGAS (BRADY) A COPEPOD OF THE SOUTHERN MACROPLANKTON

By F. D. Ommanney, Ph.D.(Lond.), A.R.C.S.

(Text-figs. 1–29)

INTRODUCTION

During the second Antarctic commission (1931–3) of the R.R.S. 'Discovery II' the programme carried out involved two extensive plankton surveys of the waters of the Falkland Sector, one between November 1931 and January 1932 and a second between October 1932 and March 1933. During each of these surveys the same general plan was adopted. North to south lines of stations were taken across the Sector, extending from sub-Antarctic latitudes as far south as the edge of the pack-ice. These north to south lines were connected by east to west lines along the edge of the ice. A number of routine stations was also taken in particular areas where observations have been made repeatedly by the Discovery Committee's ships during several seasons—such as South Georgia, the Bransfield Strait and the South Atlantic Ocean between South Georgia and the Falkland Islands. During the winter months of 1932 these north to south lines were extended around the Antarctic Continent and a circumnavigation of the southern hemisphere was made, the ship leaving Cape Town in early April 1932 and arriving at the Magellan Straits in early October 1932.

At nearly every one of the stations taken during these cruises, both in the Falkland Sector and around the Antarctic Continent, oblique towings were made with the 1-m. stramin net (see Kemp, Hardy and Mackintosh, 1929, p. 184). From these towings a large collection of macroplankton was obtained and the Copepoda from a selection of the catches have been analysed. The following report is an attempt to give an account of the distribution, and an outline of the general life cycle, of one species of macroplanktonic copepod from among the many species (about fifty in all) which were frequently encountered in the macroplankton during the cruises.

The species, *Rhincalanus gigas* (Brady), has been specially selected for investigation for two reasons. Firstly, it is the dominant copepod throughout a very large area of the Falkland Sector of the Antarctic, with which the work of the Discovery Committee is chiefly concerned. In this area it is the dominant organism of the macroplankton, forming in its region of greatest abundance over 75 per cent, and sometimes over 90 per cent, of the total copepod catches. It may be said with some safety, therefore, that the life history of this species will typify that of the Antarctic macroplanktonic Copepoda generally, and for this reason a knowledge of its biology is of the greatest importance. The

second reason for selecting this species for investigation is its large size. The adult is 8·0–9·0 mm. in length, and the young copepodite stages are large enough to be taken by the stramin net. As a general rule the young stages of nearly all the species of macroplanktonic copepods are so small that they escape through the meshes of the 1-m. net. The young copepodites of *Rhincalanus gigas*, however, in stage iii and older, were easily retained and occurred constantly. Stage ii occurred rather less frequently and nauplii and stage i occurred only, presumably, when present in great abundance in the water. Some idea at least of the course of events during the life cycle of the species can therefore be obtained from the catches taken with the towed 1-m. net.

The author is deeply indebted to Mr G. E. R. Deacon and to Mr F. S. Russell, D.S.C., for much help and criticism. In the many hydrological problems which arose during the course of this work the advice of Mr Deacon was invaluable.

METHODS

The stations at which the Copepoda from the 1-m. nets were examined during the seasons 1931–2 and 1932–3 in the Falkland Sector, and during the winter months around the Antarctic Continent, are shown in Figs. 1 *a*, *b*, 2 *a*, *b*, and 3 and Tables I *a–c*. It will be seen that only a selection of the total stations taken have been dealt with. The catches were examined from 70 stations in the Falkland Sector in the summer season November 1931 to February 1932 and 76 during the season October 1932 to March 1933. During the circumpolar cruise, April to October 1932, the copepod catches were examined from 108 stations.

Whenever possible, as will be seen from the tables, two towings were made with the 1-m. stramin net, one using the net as a closing net and towing obliquely from as nearly as possible 250 m. to as nearly as possible 100 m., and the other towing as nearly as possible from 100 m. to the surface. Both the upper and the lower nets were always fished for the same length of time at every station: the upper for 20 minutes and the lower for 30 minutes. Two 70-cm. silk nets were also attached to the warp and towed through the same depths, one in conjunction with each of the 1-m. nets. This paper, however, is concerned only with the catches obtained by the latter. All four nets (two 1 m. and two 70 cm.) were towed together on the same warp, and the messenger, which closed the lower nets at about 100 m., was released after the two upper nets (100–0 m.) had been taken on board. A Kelvin tube, attached to a stream-lined lead, was placed between the two upper nets to indicate the depth from which they were towed, and a Bourdon tube depth gauge was shackled to the end of the warp to indicate the depths between which the lower nets were fished. This instrument also gave some indication of the path of the nets through the water. (For further details of the nets and apparatus see Kemp, Hardy and Mackintosh, 1929; Ardley and Mackintosh, 1936.)

It will be seen from Tables I *a–c* and II *a–c* that the actual depths through which the nets fished varied constantly and widely from the 100–0 m. and 250–100 m. which were aimed at in every case. The warp was always hauled in at a constant speed of 10 m. a minute, and the speed of the ship when towing was kept as nearly as possible at two

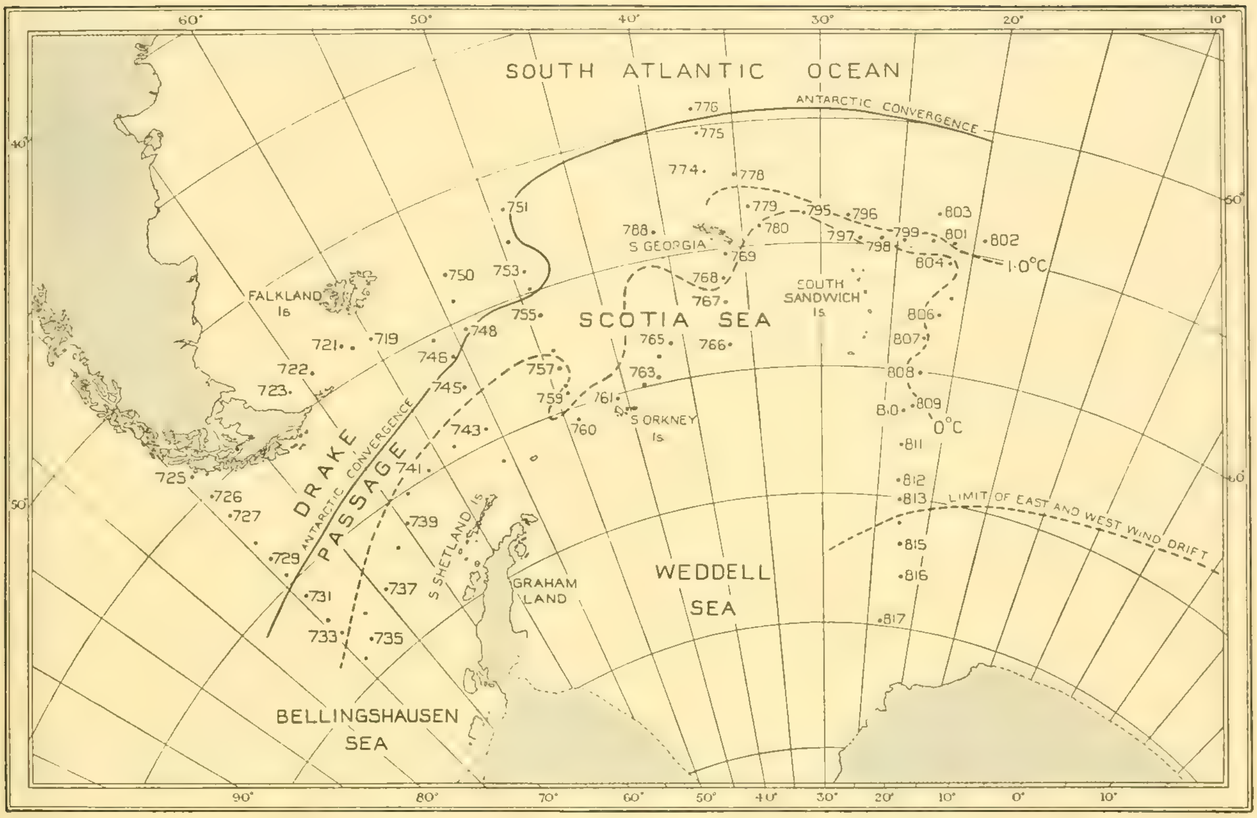

Fig. 1 *a*.

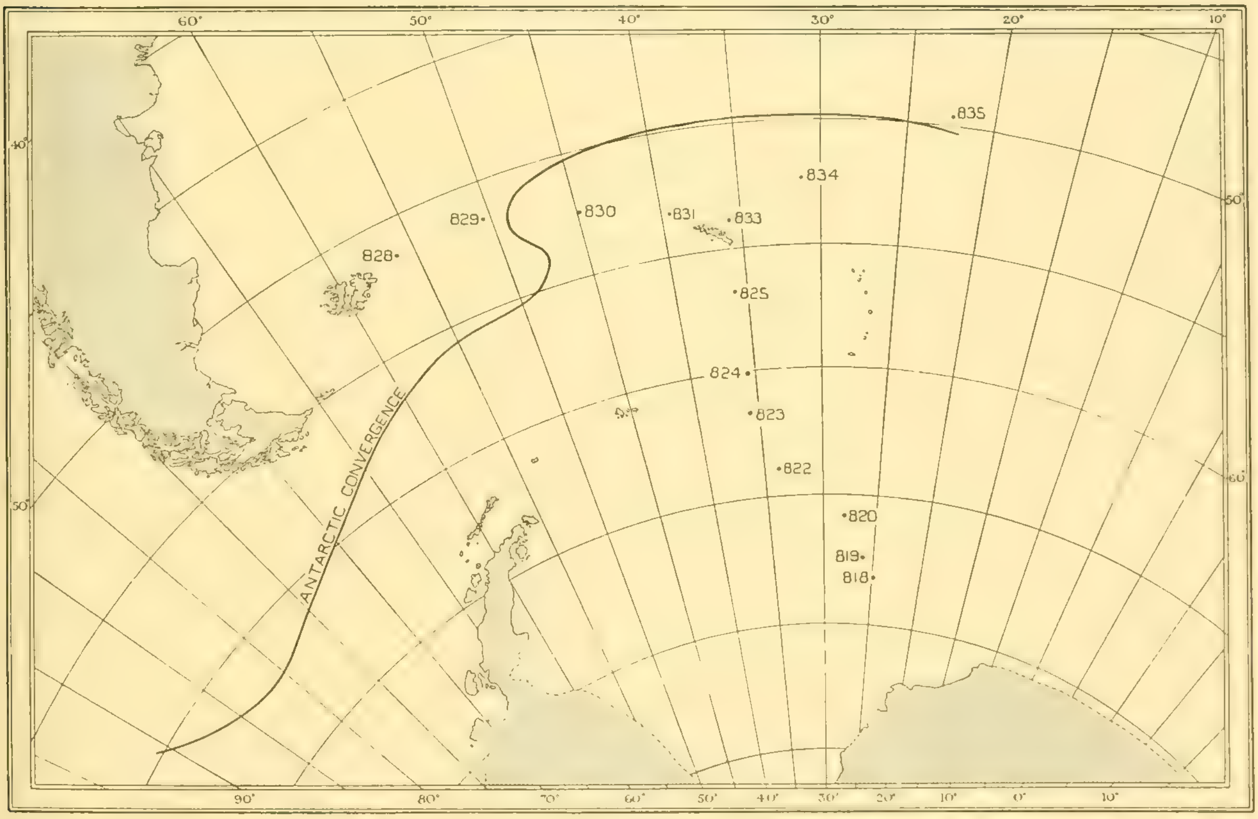

Fig. 1 *b*.

Charts showing stations taken by the R.R.S. 'Discovery II' in the Falkland Sector of the Antarctic in the season 1931–2. Only those stations have been numbered at which the Copepoda were examined. *a*. November 1931 to mid-January 1932. *b*. Mid-January 1932 to February 1932.

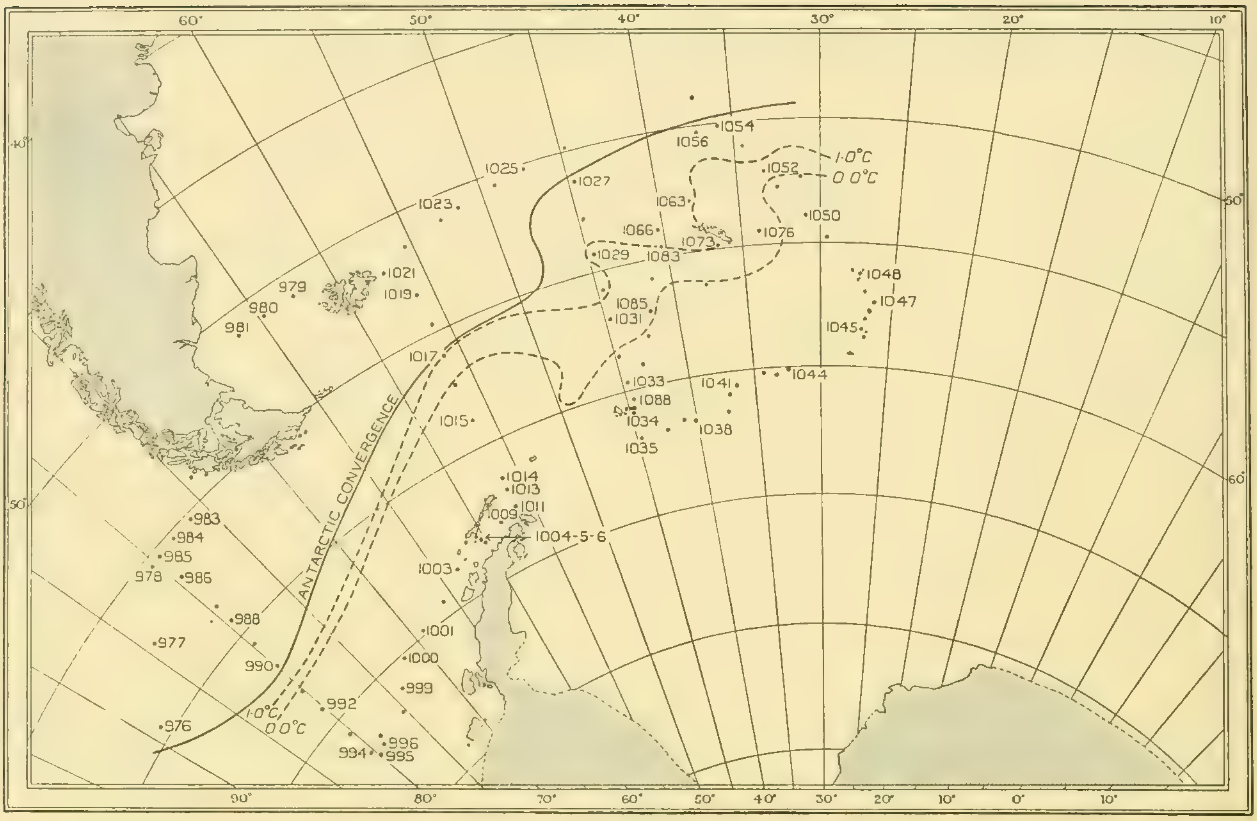

Fig. 2*a*.

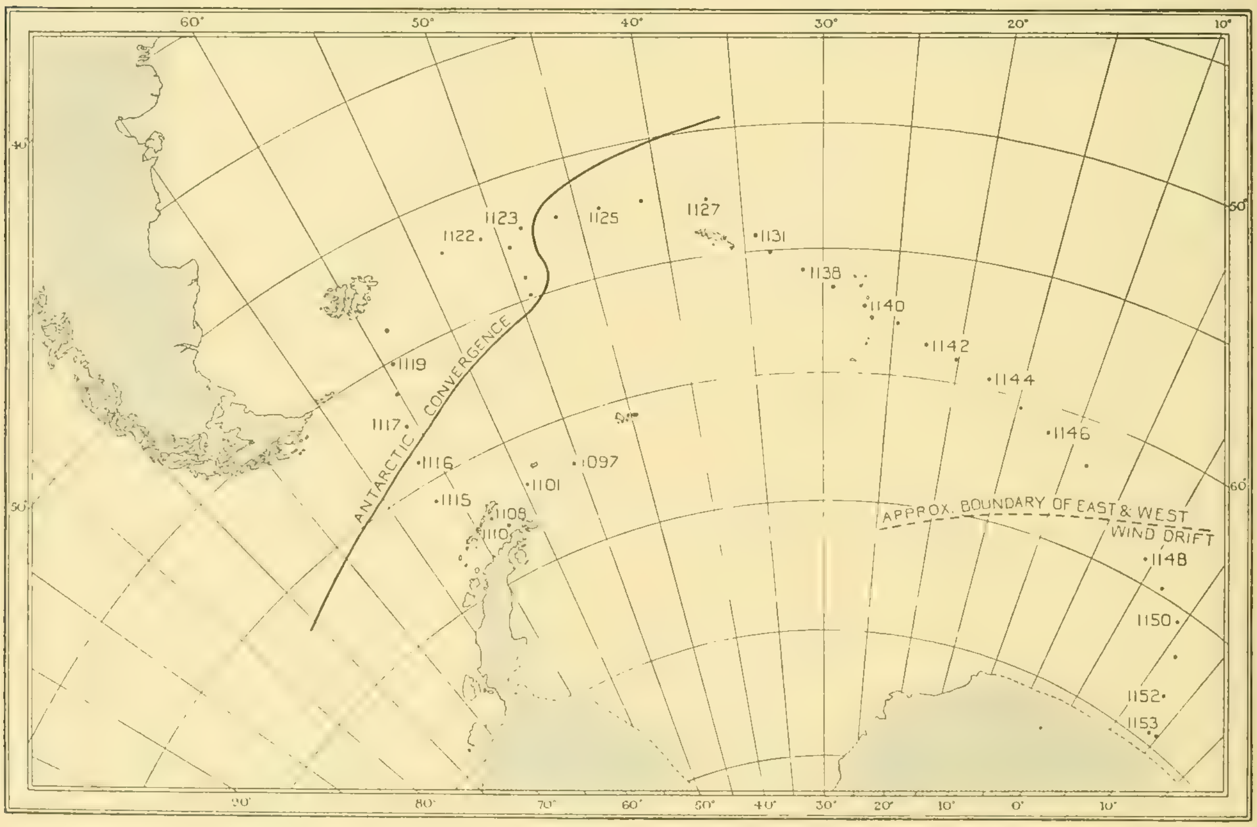

Fig. 2*b*.

Charts showing stations taken by the R.R.S. 'Discovery II' in the Falkland Sector of the Antarctic in the season 1932–3. Only those stations have been numbered at which the Copepoda were examined. *a*. October to December 1932. *b*. February to March 1933.

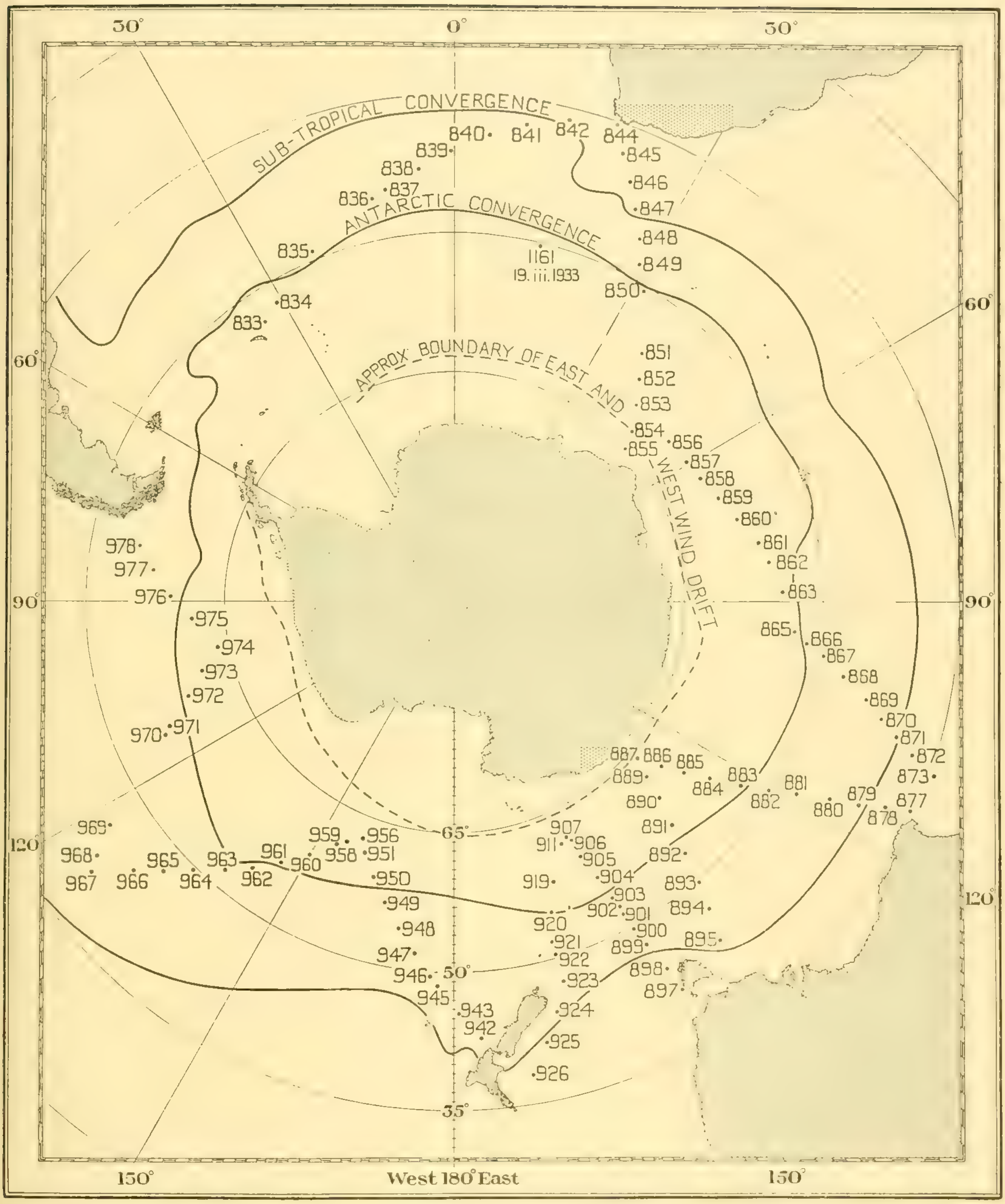

Fig. 3. Chart showing stations taken by the R.R.S. 'Discovery II' around the Antarctic Continent during the winter months, February to October 1932. Only those stations have been numbered at which the Copepoda were examined.

knots. Nevertheless it was never possible to keep the ship's speed absolutely constant during any one towing or to be sure that the speed of the ship was exactly the same at successive towings, and with small variations in the speed the depth of the nets varied widely—the nets rising towards the surface with increased speed and falling with decreased speed. Thus the shallowest surface haul was at St. 735, where the net fished from 62 to 0 m., and the deepest was at St. 748, where the net fished from 180 to 0 m. There were many gradations between these two extremes. The deep net also frequently fished through depths which varied widely from those aimed at. The following stations may be quoted as instances of the kind of variation which occurred:

St. 727: 310–170 m.	St. 769: 342–150 m.
733: 300–140 m.	776: 356–170 m.
746: 306–124 m.	802: 320– 70 m.
748: 204–138 m.	815: 314–188 m.
757: 320–126 m.	830: 356–140 m.

Similar figures may be found throughout the tables. The question of applying some correction to these hauls so as to standardize the catches should therefore be given consideration.

In spite of the somewhat wide variations in the depths at which the surface net began towing it can be shown diagrammatically (Fig. 4) that the oblique path of the

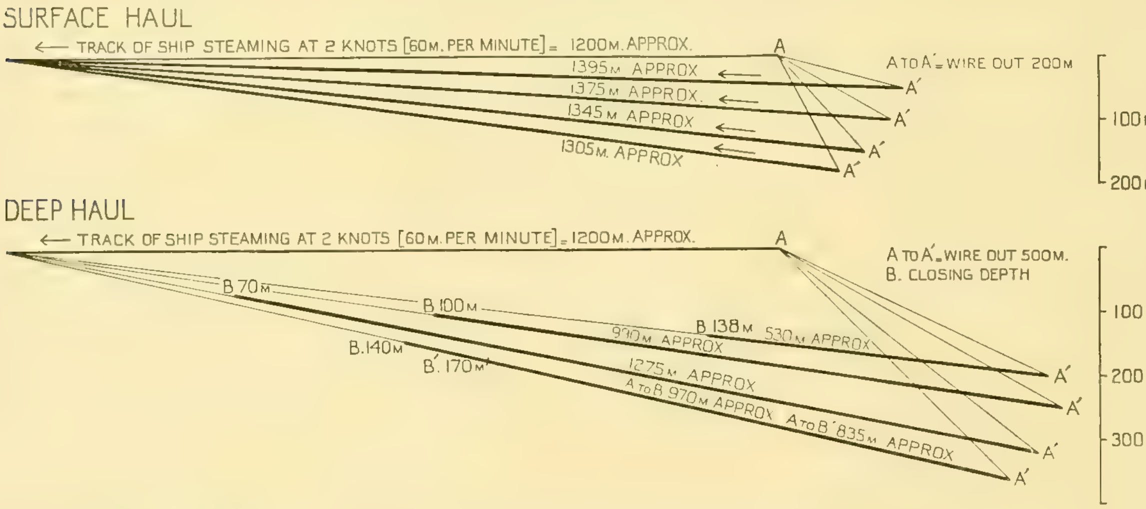

Fig. 4. Diagram illustrating the variations in the length of the oblique tow with variations in the commencing depth of the surface and deep hauls and in the closing depth of the deep net.

net to the surface was in reality not widely different at every haul. In Fig. 4 a number of surface hauls have been plotted which begin at depths varying from 50 to 180 m., the widest limits of error met with in the surface towings under consideration. The commencing depth aimed at in every case was 100 m., which, as the diagram shows, gives a towing of approximately 1375 m., assuming the path of the net to the surface to be a perfectly straight oblique line. A haul with a commencing depth of 50 m., however, gives a towing 1395 m. in length (approximately). This is only 20 m. in excess of the length aimed at (1375 m.), and in view of the length of the tow and of the circumstances

and conditions under which the hauls were necessarily carried out, it is an almost negligible error. Greater commencing depths than 100 m. give towings varying somewhat more widely from the length aimed at. A commencing depth of 180 m. gives an oblique towing of about 1305 m., 70 m. too short. Even this, however, represents an error of only 5·3 per cent, and it was seldom that the surface net reached so great a depth as 180 m. The commencing depth was more usually between 100 and 150 m.—the latter depth giving a towing of about 1340 m., an error of only 2·2 per cent.

The deep hauls, when plotted in the same way, show greater errors, which arise mainly from the varying depths at which the net closes. The depth aimed at, 250–100 m., gives a towing about 990 m. in length, and it may be seen from Fig. 4 that such a haul as that made at St. 802, 320–70 m., gives a tow of about 1275 m., a difference from that aimed at of 285 m. A towing such as that at St. 776, however (356–170 m.), gives a haul of about 835 m. only, a difference from that aimed at of 155 m.

Nevertheless, in spite of the wide variations in the depths through which the deep net was towed, it was decided to make no attempt to apply a standardizing correction to the catches, firstly because it is impossible to find any simple or constant correction to apply, and secondly because the nets used cannot be regarded as instruments which give a quantitative estimate of the plankton. The results obtained with them must be looked upon as strictly qualitative, and the numbers in the catches must be taken to indicate only relative abundance or relative scarcity.

The path of the net actually traced out during an oblique towing is never under any circumstances a perfectly straight oblique line, since, as already explained, the net rises and falls with variations in the speed of the ship, which can never be kept absolutely constant. Again, very many factors introduce inaccuracies into the results obtained with towed nets of this description, such as the local swarming of the plankton, variations in the depth of the plankton with the weather, and the possibility of the nets fishing to some extent when being paid out or handled at the surface and so on. Hardy and Gunther (1935) have drawn attention to this general aspect of plankton investigation (p. 27) and it may be once more emphasized here. "We are in this work concerning ourselves only with big differences; the very nature of the distribution of the plankton we are studying and the necessary limitations to our methods in the field will not allow us to attempt the establishment of small differences. When we are comparing one region represented by 5000 *Corethron* with another represented by 562,000, what does it matter if that 5000 is really 7500 or 2500, or again if the 562,000 is really 281,000 or 743,000?" Similarly with *Rhincalanus gigas*, if we are comparing one region represented by 15,300 *R. gigas* with one represented by 5730 it makes no difference to the final picture of the distribution of the species if the former number is really 13,250 or 18,470, and the latter number 7250 or 4320. So that even if a standardizing correction could be applied to the hauls the labour of applying it would certainly not be repaid.

As will presently be seen (pp. 286–7) we are in this report concerned with two layers of water in the area studied, an upper and a lower one. The boundary between these two layers of water is usually only known to the nearest 50 or 100 m., so that the length of

the path of the deep net in the upper and in the lower layer is only very approximately known. The proportion of the catch, therefore, which properly belongs to each layer of water cannot be ascertained. All that can ever be said is that part at any rate of the catch in the deep net belongs to the lower layer, except at certain stations (marked with two asterisks in Table II *a–c*, p. 369) where the lower layer approaches the surface to such an extent that the whole of the path of the deep net lies within it. Similarly the catch in the upper net either belongs wholly to the upper of the two water layers under consideration, or else, when the boundary between the layers lies near the surface as at the stations marked with two asterisks in Table II *a–c*, it must contain a percentage which belongs to the lower layer. The variation in the depth of the boundary between these two layers and the mixing which always takes place across it are, therefore, factors which introduce large but unknown variations into the catches and which make it useless to attempt any exact interpretation of the figures.

Little need be said about the methods employed in the laboratory during this work. In every case the samples were fixed and preserved in 10 per cent formalin and were analysed by direct inspection and counting, using a binocular microscope and a Petri dish, in which the sample was spread out. When the samples were too bulky for complete examination they were fractioned over a card marked in eighths or tenths and a fraction only of the sample was examined. Very often, after a fraction of the whole sample had been examined, it was necessary to take yet another fraction of the Copepoda left after the other organisms had been counted, so that fractions of a fiftieth or a hundredth of the total Copepoda are not uncommon in the analyses. This method of analysis is, again, only approximately accurate when fractions are examined, and the smaller the fraction of the total sample examined the greater the error in the analysis.

Many of the samples were analysed on board the 'Discovery II' during the cruises, but a large number of the copepod analyses were repeated on shore.

HYDROLOGY OF THE AREA

It is not necessary here to enter into a detailed description of the hydrology of the area covered by these cruises. For the hydrology of both the Falkland Sector of the Antarctic and of the Southern Ocean reference should be made to the accounts published by Deacon (1933 and 1936). It is perhaps desirable, however, to give the very briefest account possible of the hydrological conditions in the area traversed, so far as they are likely to affect the catches with which this paper is concerned.

Antarctic Seas generally are characterized by a cold, poorly saline layer at the surface known as Antarctic surface water. It owes its low temperature and salinity to the cold Antarctic climate and to the melting of pack-ice, and it has an average depth of about 200 m. Antarctic surface water streams away from the Antarctic Continent and its surrounding pack-ice in a northerly and easterly direction and becomes part of the general eastward movement around the Southern Hemisphere known as the West Wind

Drift. Where it meets with warmer, more saline sub-Antarctic water the Antarctic surface water sinks along a well-defined line known as the Antarctic convergence (Deacon, 1933, pp. 190–3). From one side of the Antarctic convergence to the other there is a pronounced difference in surface temperature which is more marked at some places than at others. The Antarctic convergence (Figs. 1–3) is thus held to be the boundary between the Antarctic and sub-Antarctic Zones. Beneath this northward- and eastward-flowing Antarctic surface layer is a very much thicker layer of warmer water flowing southwards from the Atlantic, Pacific or Indian Oceans, known as the warm deep water. "A certain amount of mixing must always take place between the two layers across the discontinuity layer which separates them, especially in winter.... Warm deep water has never itself been found at the surface although it has been found with its maximum temperature at a depth of only 100 m.: it is always covered with Antarctic surface water" (Deacon, 1933, p. 180). Along the Antarctic continental shelf, and in certain other places, warm deep water wells upwards towards the surface. In the Falkland Sector this upwelling is most pronounced along the west coast of Graham Land and the South Shetlands "and along that part of the ridge known as the Scotia Arc which joins Joinville Island to the South Orkney Islands and the South Sandwich Islands" (Deacon, 1933, p. 181).

Thus throughout the whole of the area covered by the present report two layers of water must be taken into consideration—the northward- and eastward-moving Antarctic surface water and the southward-moving warm deep water below it. The 100–0 m. net was almost always towed entirely in the Antarctic surface layer, but, as Tables II *a–c* show, the lower net usually fished partly in the Antarctic surface layer and partly in the warm deep layer. At a few stations, however, mostly in the positions mentioned above, that is on the continental shelf or on the Scotia Arc where warm deep water wells upward to the surface, the deep net was towed entirely in the warm deep water. These stations are marked with two asterisks in Table II *a–c*. Those marked with one are stations at which the upper net fished entirely in Antarctic surface water and the lower net partly in Antarctic surface water and partly in warm deep water. Those which bear no asterisk are stations at which both nets fished in Antarctic surface water since the discontinuity layer lay below the range of the hauls. The tables show that at most of the stations in the northerly part of the Antarctic Zone, where the discontinuity between the two layers lay deep down, the deep net was worked in Antarctic surface water. During the circumpolar cruise the deep net was almost always towed partly in both layers of water, but at certain stations it was wholly in the deep layer. These stations were situated either on the continental shelf or on the boundary between the East and West Wind Drift currents shortly to be described, where again warm water wells upward towards the surface.

In the Falkland Sector water passes through the Drake Passage in an easterly direction, the West Wind Drift current being here constricted by the peninsula of Graham Land on the south and by South America on the north. The Antarctic convergence passes through the Drake Passage (Figs. 1, 2 and 3), and in about 55° S and 49° W it turns north

between the Falkland Islands and South Georgia. It turns east again in about 53° S and passes north of South Georgia across the South Atlantic.

North of the Antarctic convergence sub-Antarctic water of the West Wind Drift passes through the Drake Passage from the Pacific Ocean around the east coast of the Falkland Islands into the Atlantic Ocean. South of the convergence the water flowing eastwards through the Drake Passage originates in the Bellingshausen Sea and passes into the South Atlantic through the western Scotia Sea and around the western end of the island of South Georgia. North of the island it resumes its more eastward course between 50 and 55° S. This is really part of the West Wind Drift, but in this report it will be known as the Bellingshausen Sea current to distinguish it from the West Wind Drift water north of the convergence.

In the Drake Passage and Scotia Sea the warm deep water flowing southwards probably originates in the Pacific Ocean, and that in the Atlantic Ocean north and east of South Georgia originates in the Atlantic (Deacon, 1933, p. 237).

In the Weddell Sea, on the eastern side of the Graham Land peninsula, there is a cyclonic current system. South of 66° S. and east of 15° E water flows westwards into the Weddell Sea. It circulates in a clockwise direction along the east coast of Graham Land and flows out in a north-easterly direction towards the South Sandwich Islands across the eastern Scotia Sea. This Weddell Sea current is colder and more saline than the Bellingshausen Sea current and carries pack-ice and numerous icebergs. Where it meets with the warmer, less saline Bellingshausen Sea current in the Scotia Sea and in the South Atlantic east of South Georgia it both mixes with it and sinks below it, but its influence is perceptible in the South Atlantic as far east as longitude 30° E.

A tongue of water of Weddell Sea origin runs north-westwards in the Scotia Sea between the South Orkney Islands and South Georgia, and another passes in a north-westerly direction along the east coast of South Georgia. These are visible in the shape of the isotherms calculated from the average temperature of the surface 100 m. at each station[1] (Figs. 5, 6). The bend of the 0 and 1·0° isotherms westwards in the Scotia Sea in the season 1931–2 (Fig. 5) and again in the season 1932–3 (Fig. 6) shows where the tongue of Weddell Sea water projects into the Bellingshausen Sea current. Similar westward bends in the 0 and 1·0° isotherms, but particularly in the latter, are discernible east of South Georgia, where there is another westerly projection of Weddell Sea water into the Bellingshausen Sea current. A small eddy of Weddell Sea water passes westwards around Joinville Island and flows into the southern part of the Bransfield Strait (Fig. 6).

In the Antarctic surface water of the Falkland Sector there are, therefore, two main masses of water—the Bellingshausen Sea current, passing from the Bellingshausen Sea into the South Atlantic through the Drake Passage and around the western end of the island of South Georgia, and the Weddell Sea current, passing north-eastwards from the Weddell Sea across the Scotia Sea towards the South Sandwich Islands. In the

[1] It should be noted that temperature, throughout this report, is expressed as the average of the readings between 0 and 100 m. The isotherms also are calculated on this basis.

Scotia Sea south of South Georgia and in the South Atlantic east of South Georgia the waters of the two origins mix.

Beneath the surface water in the Weddell Sea is a warm deep current flowing westwards into the Weddell Sea from the Indian Ocean south of 66° S and east of 15° E. It follows the clockwise course of the surface water in the Weddell Sea and flows out as a cold deep current (cooled on its passage around the Weddell Sea) towards the South Sandwich Islands. "As soon as it meets warm deep waters of Pacific or Atlantic origin it both sinks below them and mixes with them" (Deacon, 1933, p. 229).

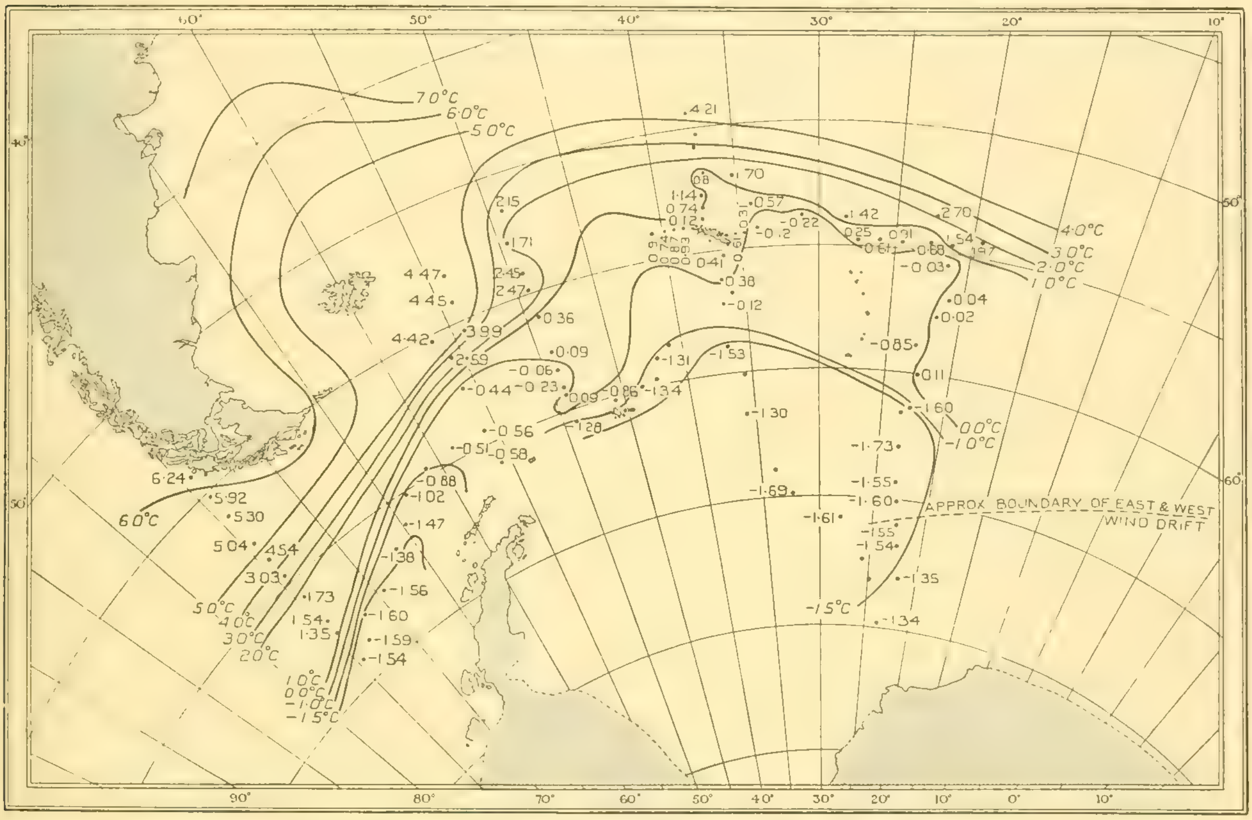

Fig. 5. Isotherms (° C.), calculated from the average temperature of the surface 100 m., in the Falkland Sector of the Antarctic, November 1931 to mid-January 1932.

With regard to the area traversed during the circumpolar cruise outside the Falkland Sector, only two hydrological features, in addition to the two layers of water already described (Antarctic surface water and warm deep water), are of interest to us in the present report. The first of these is the West Wind Drift which forms a continuous easterly movement of Antarctic surface water, with a strong northerly component, all round the Antarctic Continent. The second is the exactly opposite movement which takes place round the Antarctic Continent in the region of easterly winds south of about 65° S. This current, flowing westwards around the coast of Antarctica, is known as the East Wind Drift, and it is this current which flows into the Weddell Sea south of 66° S and out of it again along the east coast of Graham Land as the north-easterly Weddell Sea current. The boundary between the West Wind and East Wind Drift currents is

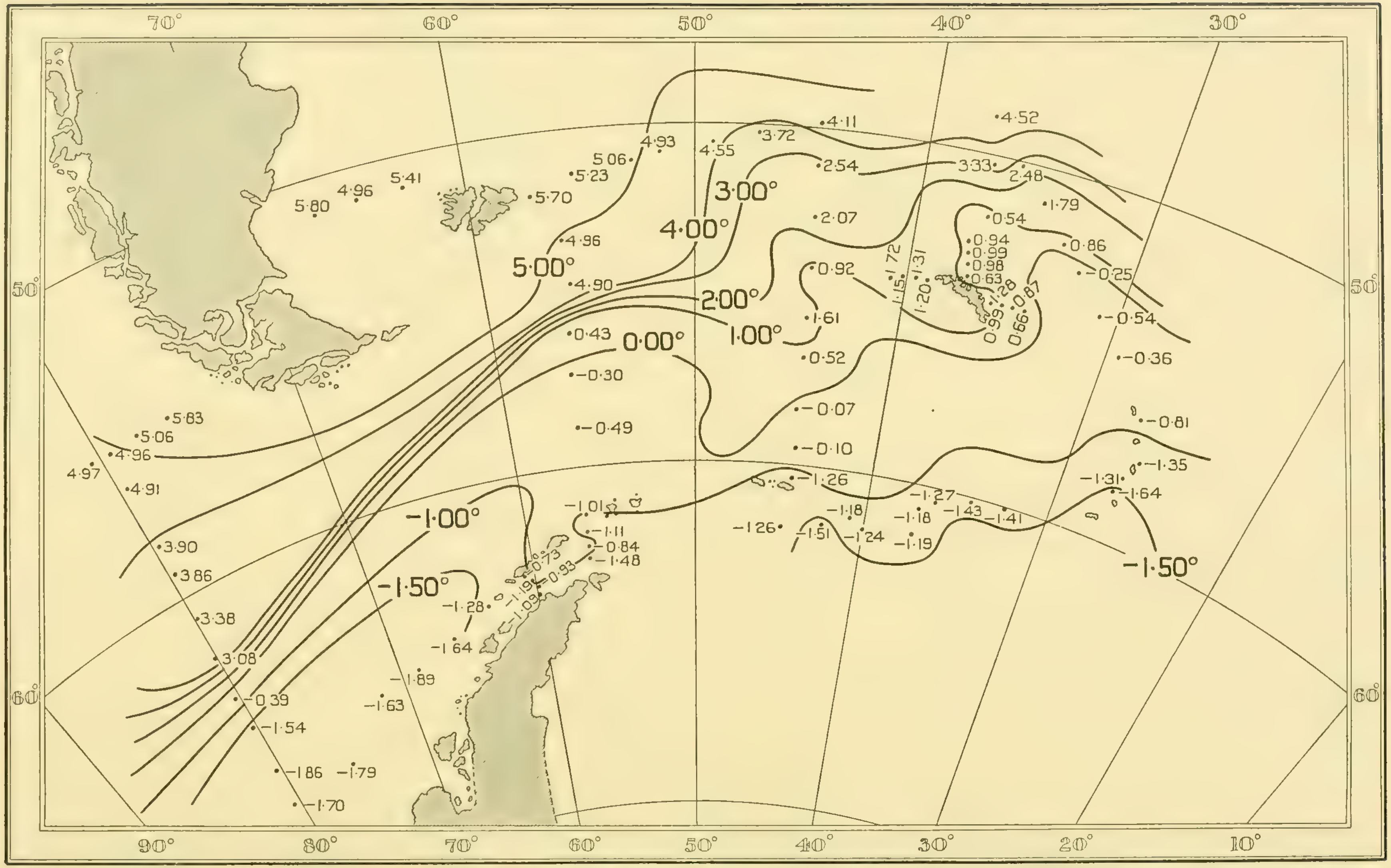

Fig. 6. Isotherms (° C.), calculated from the average temperature of the surface 100 m., in the Falkland Sector of the Antarctic, October to December 1932.

indicated as a dotted line in Figs. 3 and 11 and is a region of very marked upwelling of warm deep water towards the surface. These regions of upwelling deep water are of importance, since they have pronounced effects upon the plankton.

In the surface water of each of the two main water masses in the Falkland Sector—the Weddell Sea current and the Bellingshausen Sea current—it has been found possible to distinguish four main types of water each having fairly distinctive characters. Figs. 5, 6 and 7 show the isotherms in the Falkland Sector during the seasons 1931–2 and

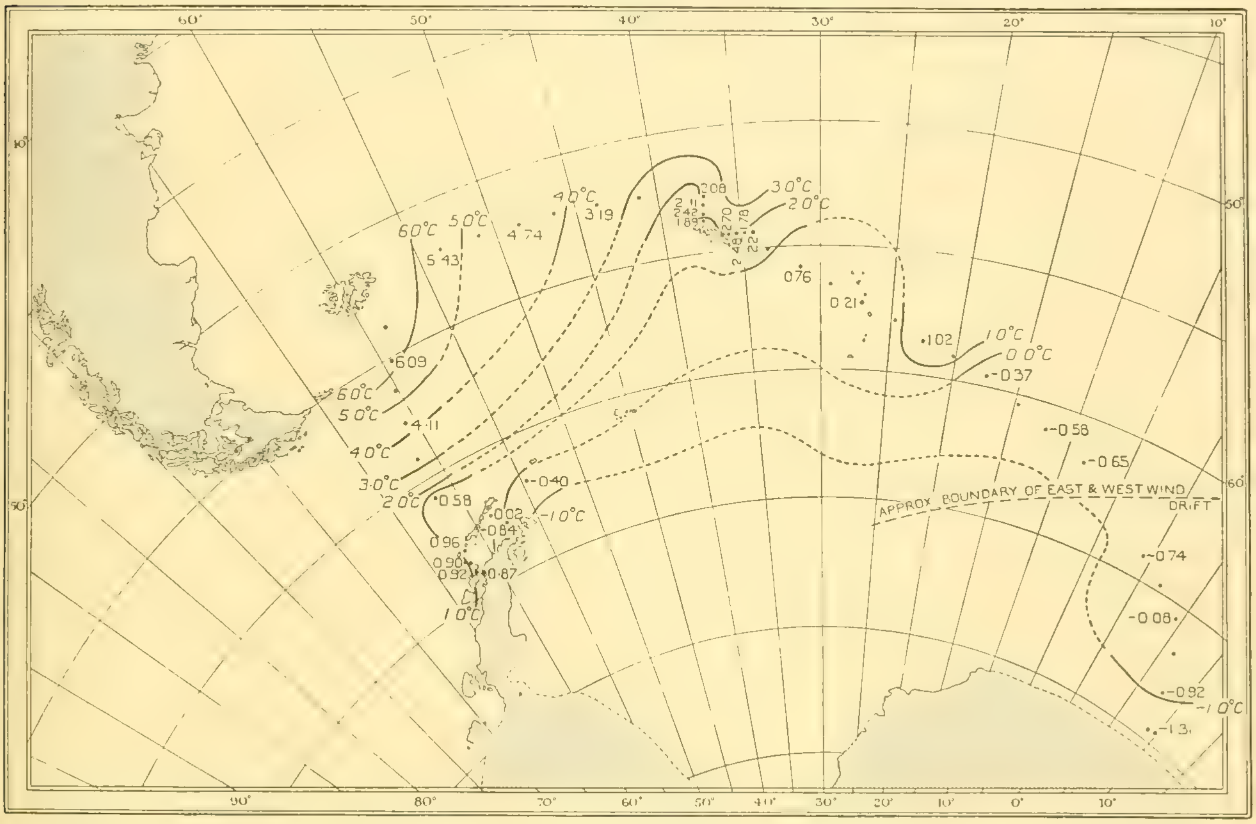

Fig. 7. Isotherms (° C.), calculated from the average temperature of the surface 100 m., in the Falkland Sector of the Antarctic, February, March 1933. (Dotted lines represent the conjectural position of the isotherms.)

1932–3, based upon the average temperature of the surface hundred metres at each station. The following four types of water are distinguishable:

(*a*) Very cold water with a temperature less than – 1·5° C., carrying pack-ice which is not melting.

(*b*) Warmer water with a temperature between – 1·5 and – 1·0° C., carrying melting pack-ice.

(*c*) Water with a temperature between – 1·0 and 0·0° C., in which pack-ice has recently melted.

(*d*) Water with a temperature between 0·0 and 1·0° C. in the Weddell Sea current and between 0·0 and 2·0° C. in the Bellingshausen Sea current.

Thus there is established a conception of the "age" of water of various types, since

type (*d*) will have drifted farther from its source of origin than type (*c*), and type (*c*) than type (*b*) and so on. Water carrying unmelted pack-ice in the centre of the Weddell Sea and far south in the Bellingshausen Sea is conceived as being the "youngest" type of water. It was met with only to a small extent in the season 1931–2 in the Bellingshausen Sea, since the edge of the ice lay to the northward in the Drake Passage in the spring of that year. The chief value of this classification for the purpose of this report is that it provides a useful means of distinguishing between the various regions in which the catches were taken and it will be shown that to a limited extent each type of water is characterized by a slightly different fauna.

During the season 1931–2 few observations were taken after the middle of January upon which to base conclusions as to the changes in the disposition of the four types of water as the season advanced. The surface temperatures at Sts. 824 and 825 ($-0{\cdot}18$ and $2{\cdot}13^\circ$ C.) seem to indicate that a retreat southwards of Weddell Sea water carrying pack-ice took place between the middle of December (St. 766) and the middle of January (Sts. 824 and 825). There were no deep observations at Sts. 824 and 825, however, by which this can be confirmed. During the season 1932–3 a line of stations was taken in early February across the eastern end of the Drake Passage (Sts. 1115–1120), another in late February between the Falklands and South Georgia (Sts. 1121–1131), and another in March from South Georgia across the Weddell Sea current to the pack-ice edge in 69° 22′ S, 9° 37·5′ E (Sts. 1137–1153). Fig. 7 shows the position of the isotherms, again calculated from the average temperature of a stratum 100 m. deep, at the eastern end of the Drake Passage in early February and in the Weddell Sea in March as found on these lines of stations. The figure shows a clearly perceptible southward movement of the isotherms in the Drake Passage in February as compared with the conditions in this area in November of the same summer (Sts. 1014–1020; Fig. 6). In the Weddell Sea in March (Fig. 7) this southward movement of the isotherms is even more pronounced, compared with conditions at the end of November and the beginning of December (Fig. 6). It is doubtless connected with the break up and retreat southward of the pack-ice as the season advances. Mackintosh (1934, p. 130, fig. 46) figured the position of the pack-ice in the South Georgia–South Sandwich area in successive months during the season 1930–1, and illustrated its retreat southwards from a position near South Georgia in October to the middle of the South Sandwich group in February. Mackintosh's figure shows that the movement of the ice from the vicinity of South Georgia to the south-east was less pronounced in the season 1930–1 than in the season 1931–2 with which we are concerned in this report. In early December 1931 the pack-ice was near St. 767 (Fig. 1 *a*), which was worked among drift ice and bergs in about the latitude of the northern end of the South Sandwich group. By the end of January it had retreated southwards to the position of St. 823 (Fig. 1 *b*) in the latitude of Elephant and Clarence Islands. This was very far south of its position in the previous January, as shown by Mackintosh, when the line of the ice-edge ran approximately from the South Orkneys to the northern end of the South Sandwich group. In the season 1932–3 pack-ice was met with at the southern end of the South Sandwich group at the end of

November (St. 1045), but in March open water was found throughout the whole length of the line in that month from St. 1138 to St. 1153.

PREVIOUS WORK

The species *Rhincalanus gigas* was first described by Brady (1883) from the collections of H.M.S. 'Challenger', and subsequently Giesbrecht (1902) described a species from the collections of the Belgica Expedition which he called *R. grandis* and which he believed to be identical with the *R. gigas* of Brady. Wolfenden also found this species in the Gauss collections (Wolfenden, 1911) and in the Discovery collections (Wolfenden, 1908), and established that the species described by Brady and Giesbrecht were the same. *R. gigas* was also taken by the Terra Nova (Farran, 1929), by the Scotia (Scott, 1912) and by the Aurora (Brady, 1918) Expeditions.

Schmaus and Lehnhofer (1927) gave an account of the young copepodite stages of the species from the Valdivia collections, and it is from the description of these authors that the copepodite stages have been identified during the present work.

In the Antarctic summer of 1929–30 the floating factory 'Vikingen' took a number of plankton stations between the South Sandwich Islands and Bouvet Island and between the South Orkney Islands and the South Sandwich Islands. The collections from these stations, together with one station taken by the 'Norvegia' in 1928, form the subject of a paper by Ottestad (1932), in which the author dealt with the biology of certain of the more important species of macroplanktonic Copepoda. In the short section devoted to *R. gigas* the author arrived at certain conclusions which are to a large extent confirmed in the present report.[1]

Hardy and Gunther (1935) have given some account of the distribution, both horizontal and bathymetrical, of the species in the immediate vicinity of South Georgia, and Mackintosh (1934) included the species in his general account of the horizontal distribution of the macroplankton in the Falkland Sector.

It is not intended in this report to give a description of the species, for which reference should be made to the accounts of Brady (1883), Giesbrecht (1902) and Wolfenden (1908, 1911). On the grounds of priority the name *R. gigas* will be used, as opposed to Giesbrecht's *R. grandis*.

DISTRIBUTION OF *RHINCALANUS GIGAS*

The material collected by the 'Discovery II' during her 1931–3 commission is far more comprehensive than that of any previous expedition, although only a portion of it has been examined and forms the subject of this paper. It will scarcely serve any purpose, therefore, to give former records of the occurrence of *R. gigas*, but it may be noted

[1] While the present report was in the press a further important paper by Ottestad has appeared (Ottestad, P., 1936. On Antarctic Copepods from the "Norvegia" Expedition 1930–1. *Scientific Results of the Norwegian Antarctic Expeditions* 1927–8 et sqq. *Norske Vid. Akad., Oslo*, No. 15, pp. 1–44, text-figs. 1–11). The paper deals with the biology of four of the commonest Antarctic species, *Calanus acutus*, *C. propinquus*, *Rhincalanus gigas* and *Metridia gerlachei*.

that Farran (1929) found it in the Terra Nova collections as far south as 77° 30′ S near Cape Royds and Cape Evans, and Wolfenden (1911) found isolated specimens in the Gauss collection as far north as 46° S and one from 3000 m. between Tristan da Cunha and Cape Town. The 'Valdivia' also found very small numbers in the latitude of Cape Town in the Atlantic and South Indian Oceans (Schmaus and Lehnhofer, 1927). The material obtained by the 'Discovery II' gives a considerably better picture of the distribution of *R. gigas* in the Falkland Sector of the Antarctic than elsewhere, since observations in that sector were made in the summer months. The stations around the Antarctic Continent, however, were taken during the winter so that the picture they give is that of the winter distribution of the species.

HORIZONTAL DISTRIBUTION, SEASON 1931–2

Falkland Sector, November to mid-January (Table III *a*)

The figures for the lines of equal numerical distribution (Fig. 8) and of equal percentage distribution (Fig. 9) in the Falkland Sector during the first half of the season 1931–2 allow certain broad generalizations to be made. The figures should be studied in conjunction with the isotherm map (Fig. 5), in which, as already explained, the average temperature for the surface 100 m. has been plotted for every station.

The area of maximum abundance of *R. gigas* is seen (Fig. 8) to be an area where the combined hauls (250–100 and 100–0 m. together) amounted by estimation to over 10,000 individuals. In this area *R. gigas* amounted to 75–100 per cent of the total copepod catch (Fig. 9). This region of maximum abundance is seen to include the waters of the Drake Passage south of the Antarctic convergence, the western Scotia Sea, and the waters of the South Atlantic Ocean south of the Antarctic convergence lying west, north and north-east of the island of South Georgia. In the Drake Passage the area of maximum abundance extends south of the 0 and − 1·0° isotherms, but in the western Scotia Sea and South Atlantic Ocean it lies always north of the 0° isotherm. The Antarctic convergence forms the northern boundary of this area except at St. 746, which is situated practically upon the convergence itself, and at St. 776, which is also extremely near the convergence. At the latter station 86·5 per cent of the total copepod catch was made up of *Rhincalanus*, although the actual number of individuals in the combined hauls amounted to less than 10,000 (5325—see Table III *a*).

It is thus seen that the area of dominance and abundance lay in the warmer Antarctic water in the South Atlantic and western Scotia Sea, where the temperature (average for the surface hundred metres) was higher than 0° and lower than 3·0° C. This water constitutes that part of the West Wind Drift current in the Falkland Sector which originates in the Bellingshausen Sea and is known as the Bellingshausen Sea current. In the Drake Passage the area of maximum abundance extended into water from the Bellingshausen Sea having an average temperature less than − 1·0° C. (St. 739) and less than − 1·5° C. (Sts. 735 and 737). There are no observations in this particular season to show the distribution of the species in the Bellingshausen Sea itself.

Within the area of abundance certain regions may be distinguished where the popula-

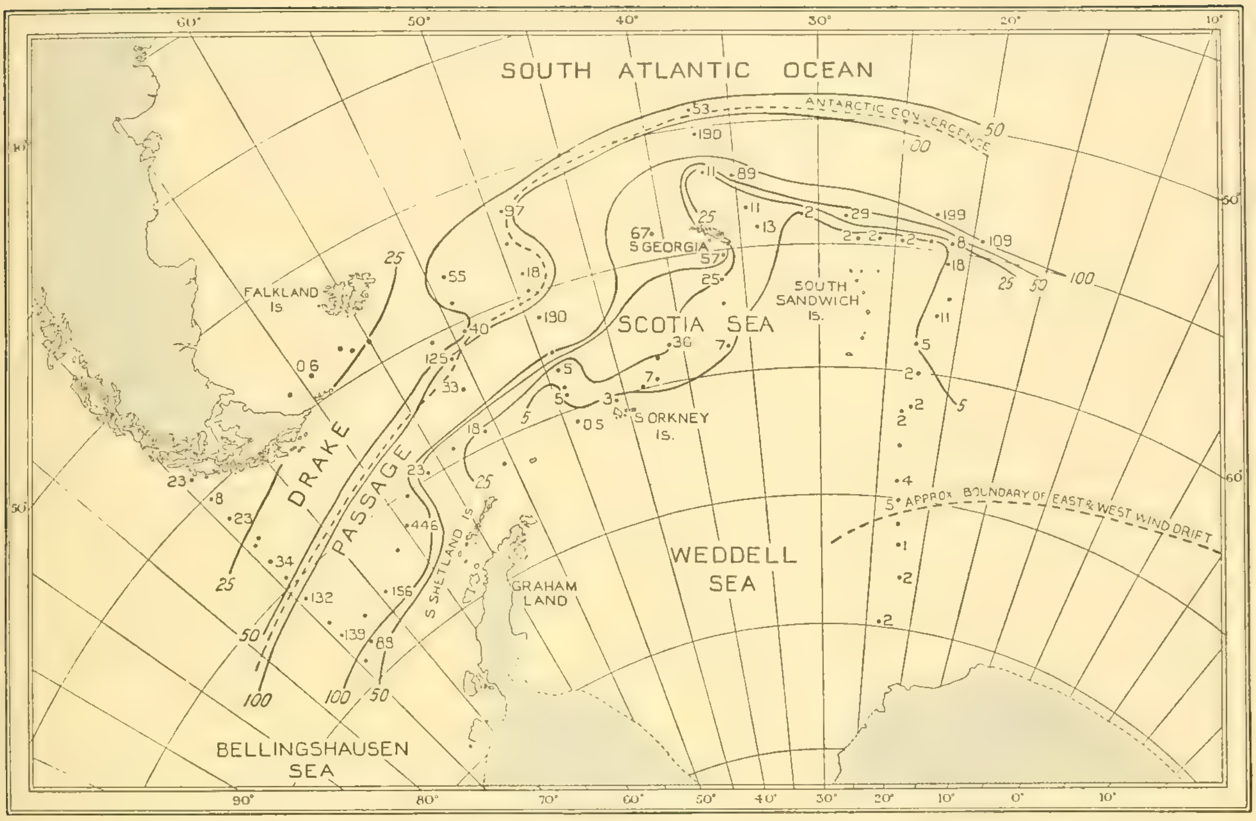

Fig. 8. Horizontal distribution of *Rhincalanus gigas* in the Falkland Sector of the Antarctic, mid-November 1931 to mid-January 1932. (1-m. nets, 250–100 m. approx. and 100–0 m. approx., both hauls combined.) Numbers represent hundreds of individuals.

Fig. 9. Percentage distribution of *Rhincalanus gigas* in the Falkland Sector of the Antarctic, mid-November 1931 to mid-January 1932. (1-m. nets, 250–100 m. approx. and 100–0 m. approx.) Numbers represent percentage of *R. gigas* in the total copepod catch in the upper and lower hauls together.

tion was particularly dense. The most evident embraced the two stations 737 and 739, in the coldest water of the Drake Passage along the pack-ice edge (Figs. 1*a*, 8). At St. 737 the estimated number in the combined hauls was 15,590, while at St. 739 it was 44,650. These two stations were situated just off the Antarctic continental shelf where warm deep water wells upwards towards the surface (Deacon, 1933, pp. 180-1). Although this is not evident from the position of the discontinuity layer at these two stations themselves (Table II *a*), they are nevertheless sufficiently near the region of upwelling for its effects to be perceptible in the plankton. Other especially large catches were taken in the area of abundance immediately south of the convergence in the South Atlantic west and north of South Georgia, and at St. 803 (Figs. 1*a*, 8) where the estimated number in the combined hauls was 19,948.

North of the Antarctic convergence in the South Atlantic, in sub-Antarctic water, is an area where *Rhincalanus* formed 50–75 per cent of the total copepod catch. Here the catches in the combined hauls amounted by estimate to between 5000 and 10,000 individuals. This area was missing in the Drake Passage where the Antarctic convergence formed a much more pronounced limit to the region of density of the species. Here the convergence sharply divided the area of maximum abundance from sub-Antarctic water in which *Rhincalanus* formed 25–50 per cent of the total copepod catch and where between 2500 and 5000 individuals were taken in the combined hauls. In the South Atlantic east of South Georgia there are no observations defining the northern boundary of the 5000–10,000 zone at this time of year, but the 5° C. isotherm may be suggested as its northern boundary.

This marked abundance of *Rhincalanus* in Antarctic water of Bellingshausen Sea origin in the Falkland Sector is in striking contrast with the comparative paucity of the species in the cyclonic current originating in the Weddell Sea (Fig. 8). Within this mass of water moving north-eastwards out of the Weddell Sea, having an average temperature less than 0° C., *Rhincalanus* amounted to less than 15 per cent of the total catch (Fig. 9) and the numbers of individuals taken at each station were less than 500 in the two hauls combined.

There is thus a pronounced difference, so far as the abundance of *R. gigas* is concerned, between the two main water masses in the Antarctic surface water of the Falkland Sector. The Bellingshausen Sea current, flowing through the Drake Passage around the western end of South Georgia into the South Atlantic, is characterized by a great abundance of this species, while the Weddell Sea cyclonic current, flowing along the east coast of Graham Land and east of South Georgia towards the South Sandwich Islands, is characterized by a relative scarcity of *R. gigas* but by a rich copepod fauna of which *R. gigas* is not an important constituent.

Between these two masses of water is an area of variable extent where their influences mingle. North of South Georgia, as already mentioned, a tongue of Weddell Sea water pushes westwards and causes the 5000 and 2500 lines of equal numerical distribution of *R. gigas* to take a bend westwards before turning eastwards again across the South Atlantic. South of South Georgia, where another tongue of Weddell Sea water pushes

northwards between the South Orkneys and South Georgia, the lines of equal numerical distribution are widely spread out (Fig. 8).

In the South Atlantic, where Weddell Sea water comes into contact with water of Drake Passage and Bellingshausen Sea origin roughly along the 1·0° C. line, the distribution lines are crowded together. They approximate to the position of the 0 and 1·0° isotherms, and where, in about longitude 23° W, the 0° isotherm takes a southward bend, the 500 and 1000 and the 25 and 50 per cent equi-distributional lines take a southward bend also. In this position the surface water appears to have a southward movement (Deacon, 1936, in press), and the course of the lines of equal distribution of *R. gigas* shows that this southward movement of warmer water has its effect upon the copepod fauna.

There is thus a sharp boundary between the copepod fauna of the South Atlantic water of Bellingshausen Sea origin and that of Weddell Sea origin. In the fauna of the former kind of water *Rhincalanus* predominates, while in the fauna of the latter type of water other species predominate, and the boundary between the two faunas lies along the 0 and 1·0° isotherm lines, which, east of South Georgia, are close to each other. Immediately north of the island, however, and in the Scotia Sea, a spreading out of the lines of equal distribution indicates a much greater degree of mingling of the influences of the two types of water. North of the island Weddell Sea influences appear to predominate in the fauna (Figs. 8, 9), while south of the island in the Scotia Sea the influence of water from the Bellingshausen Sea appears to predominate.

In general it may be said that in the Scotia Sea and in the South Atlantic east and north of South Georgia (Nov. 1931–Jan. 1932) the southern limit of distribution of *R. gigas* corresponded in position with the 0° isotherm (average of 0–100 m.). South of this line the catches amounted to less than 500 individuals and usually constituted less than 15 per cent of the copepod plankton. The 0° isotherm is also the boundary of Weddell Sea water carrying melting pack-ice or in which pack-ice has recently melted. In the southern Drake Passage, however, there is an abundance of *Rhincalanus* in water considerably colder than this, carrying melting pack-ice, which has been ascribed to the upwelling of warm deep water along the Antarctic continental shelf.

Falkland Sector, mid-January to mid-February (Table III *b*)

Not many observations were made at the end of the season 1931–2 by which changes in the distribution of the population can be judged. At the end of January a line of stations was run from the farthest point south in the Weddell Sea, at the pack-ice edge in 69° 59′ S and 23° 53′ W to South Georgia (Fig. 1 *b*). This line traversed water flowing out of the Weddell Sea on the west along the coast of Graham Land. At the four most westerly stations (822–5—see Table III *a* and Fig. 10) the catches of *Rhincalanus* amounted to between 400 and 700 individuals. Sts. 824 and 825 show a diminution in numbers compared with St. 768 in the middle of December but no marked change compared with St. 766 (Figs. 1 *a*, 8). No observations were made farther south in this water during the early part of the season with which to compare Sts. 822 and 823. In the

middle of February a line of four stations was taken between the Falkland Islands and South Georgia (Fig. 1 *b*). In this area a diminution in numbers is found compared with the conditions at the beginning of December (cf. Figs. 8, 10). This decrease, however, is very much more striking on the Falkland or sub-Antarctic side of the convergence than on the South Georgia or Antarctic side. On the sub-Antarctic side Sts. 828 and

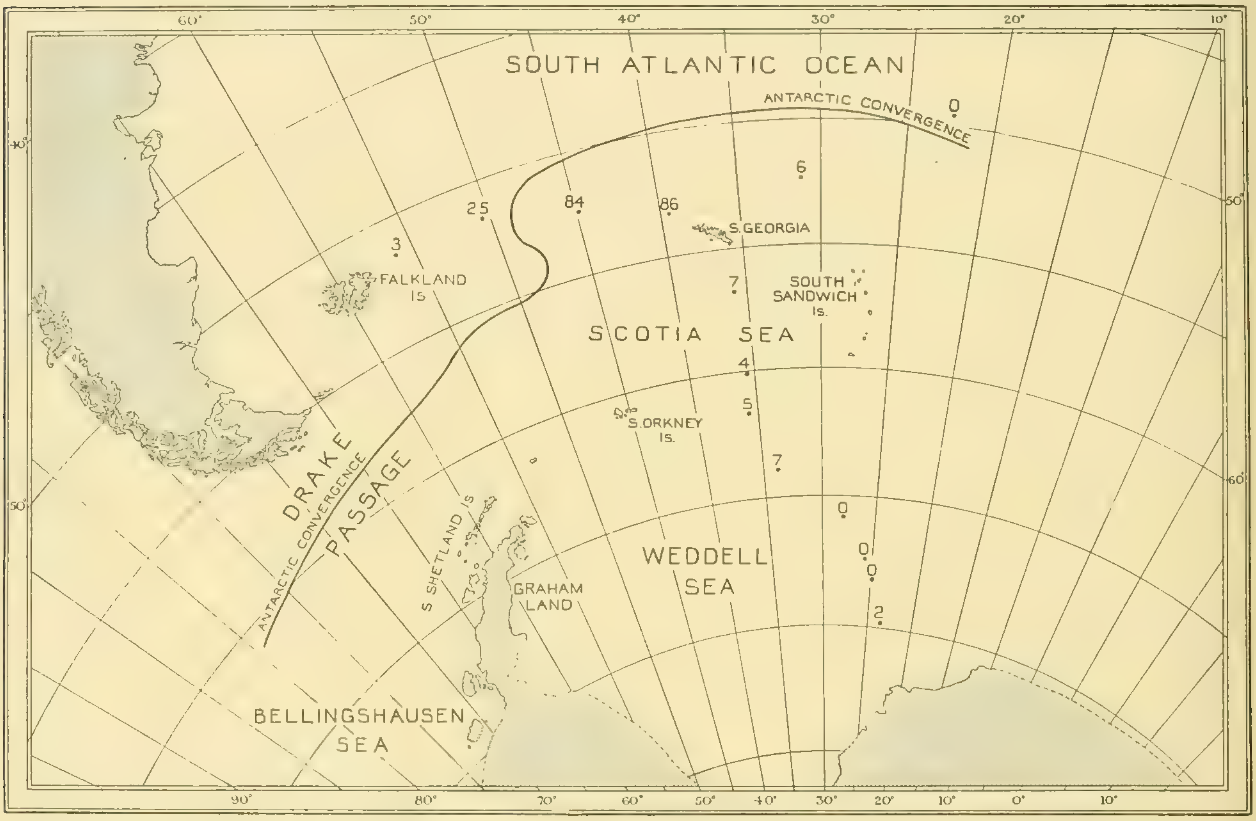

Fig. 10. Horizontal distribution of *Rhincalanus gigas* in the Falkland Sector of the Antarctic, mid-January to February 1932. (1-m. nets, 250–100 m. approx. and 100–0 m. approx., both hauls combined.) Numbers represent hundreds of individuals.

829 in February may be best compared with Sts. 750 and 751 at the end of November and the beginning of December:

St.	Date 1931	Number of *R. gigas* in combined hauls	St.	Date 1932	Number of *R. gigas* in combined hauls
750	30. xi	5475	828	17. ii	277
751	1. xii	9715	829	18. ii	253

On the Antarctic side of the convergence the catches at Sts. 830 and 831 still amounted in February to more than 8000 individuals in the two hauls combined. It is evident that at the end of the season 1931–2 the Antarctic convergence formed a barrier to the distribution of *Rhincalanus* and limited its extension into the sub-Antarctic Zone much more strictly than in November and December, when the species was found in abund-

ance in sub-Antarctic water. During December, January or February, therefore, some change apparently occurred in the copepod fauna involving the disappearance of *Rhincalanus* from the surface 250 m. in sub-Antarctic water. Further evidence of this change, limiting the northward range of *Rhincalanus*, is to be found on the line from South Georgia to South Africa at the end of the season (Fig. 11):

	St.	Date 1932	Number in combined hauls
South of Antarctic convergence	834	23. ii	594
North of Antarctic convergence	835	25. ii	0*
	836	27. ii	45
	837	27. ii	0

* Upper net only.

The above figures show, additionally, that on both sides of the convergence a far more pronounced diminution of *R. gigas* had taken place by the end of February north-east of South Georgia than had taken place by the middle of the month west of the island.

Around the Antarctic Continent, April to October (Table III *c*)

During the winter months, around the Antarctic Continent, we find that the convergence continues to limit the distribution of *R. gigas* northwards, and that the species is not found in sub-Antarctic water except in very small numbers (Table III *c* and Fig. 11). The condition found in February between the Falkland Islands and South Georgia and north-east of South Georgia thus appears to represent the winter condition of the distribution of the species.

The numbers of individuals taken on the circum-Antarctic lines of stations were very much smaller than during the summer in the Falkland Sector. Only at one station (852) on the Cape Town–Enderby Land line and at two stations on the Enderby Land–Fremantle line (857 and 862), did the combined hauls amount to more than 1000 individuals (Fig. 11).

On the line taken at the end of May from Fremantle to the ice-edge, and from the ice-edge to Melbourne (Fig. 11), the catches were very small indeed, except at the most southerly station (887) at the pack-ice edge south of Australia, where comparatively large numbers (587) of young forms and nauplii were taken. A catch of more than 100 individuals was taken at St. 883, immediately south of the convergence between Fremantle and the ice-edge, and of more than 250 individuals immediately south of the convergence on the line from the ice-edge to Melbourne. Elsewhere on these two lines the catches amounted to less than 100 individuals.

At the end of June, when returning from Melbourne to the ice-edge south of the Tasman Sea, the catches at the four stations (903–6) were extremely small, but again a catch of more than 100 individuals was taken at the station (904) immediately south of the convergence (Fig. 11). On the line from the ice-edge up to New Zealand *Rhincalanus* had almost disappeared from the catches, but here also the greatest number (more than 25 individuals) was taken at the station (919) just south of the convergence.

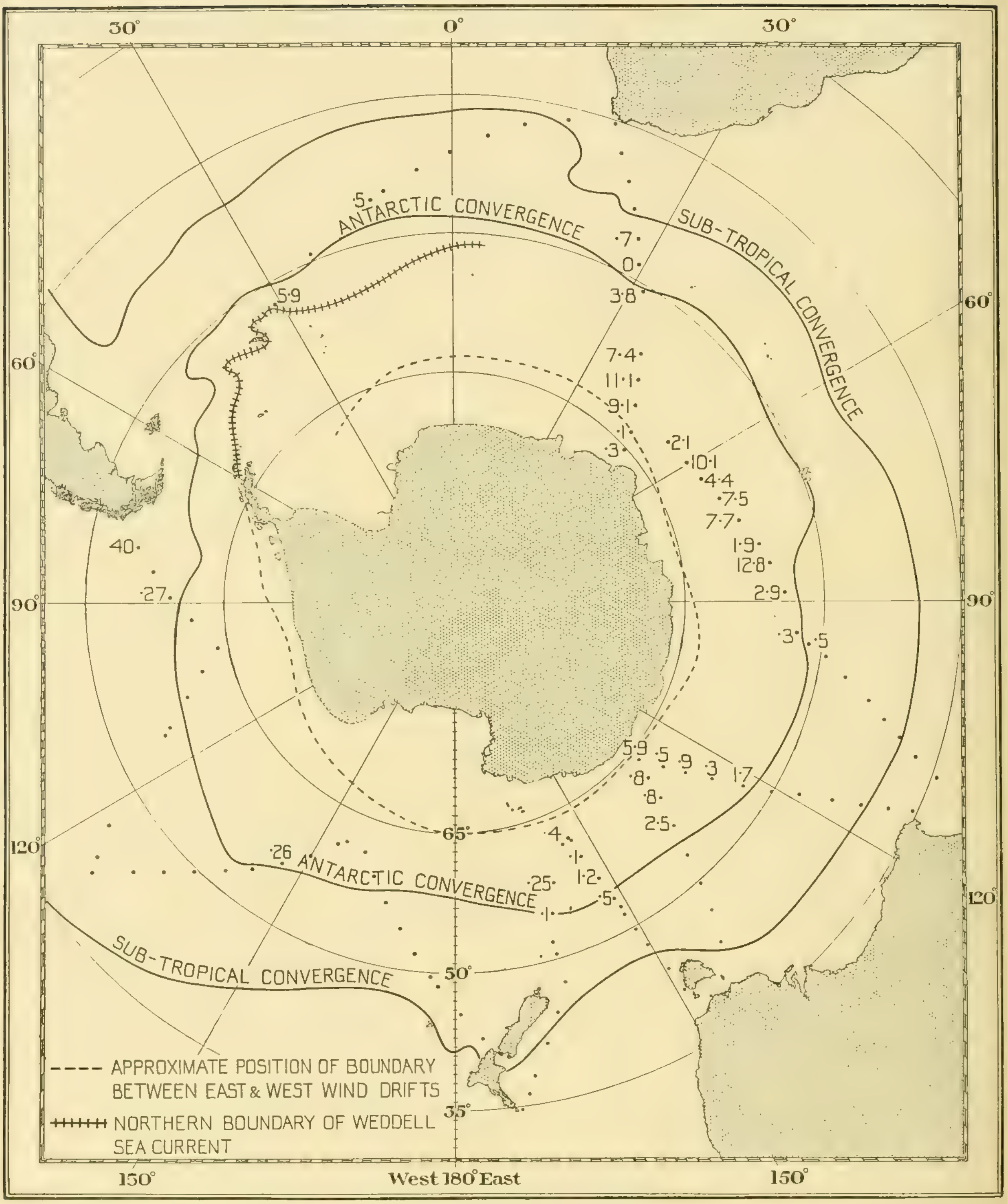

Fig. 11. Horizontal distribution of *Rhincalanus gigas* around the Antarctic Continent, winter months, February to October 1932. (1-m. nets 250–100 m. approx., 100–0 m. approx., both hauls combined.) Numbers represent hundreds of individuals.

Owing to the refitting of the ship in Auckland and to other work around New Zealand there are no observations for the two months July and August 1932. During September, however, at the beginning of which month the ship left New Zealand for the last stages of her circumpolar cruise across the Pacific Ocean, it was found that *Rhincalanus* had virtually disappeared from the catches. Only at St. 961, just south of the convergence in the western Pacific, a catch of 26 individuals was obtained (Fig. 11). *Rhincalanus* reappeared in the catches at St. 978 off Cape Horn in early October.

Two processes, then, appear to take place during the winter months around the Antarctic Continent—firstly, the restriction of *Rhincalanus* to the Antarctic zone so that the species becomes wholly Antarctic instead of mainly Antarctic, and secondly the diminution of the catches followed by the disappearance of *Rhincalanus* from the surface 250 m. after about mid-winter. It reappears in this layer again in the following spring.

BATHYMETRICAL DISTRIBUTION, SEASONS 1931–2 AND 1932–3

Falkland Sector (Table IV *a*)

It is proposed now to deal with the bathymetrical distribution of *R. gigas*, so far as it can be understood from these hauls, before considering the horizontal distribution in the Falkland Sector during the second of the two seasons covered by this work, since the horizontal distribution in the early part of the season 1932–3 can only be understood in the light of the facts revealed by a study of the vertical movements of the species from month to month.

Although the two oblique towings made with the 1-m. net from 250 to 100 m. and from 100 to 0 m. do not give a very adequate picture of the vertical distribution and movements of the plankton, yet some idea of the vertical movements from month to month can be obtained from them.

Fig. 12 shows the percentage of the total catch in the upper (100–0 m. approx.) and lower (250–100 m. approx.) hauls at stations in the Falkland Sector during November and December 1931 and January and February 1932, between South Africa and Australia in April 1932, and again in the Falkland Sector in October, November and December 1932 and February 1933. All the catches illustrated in the diagram amount to over 500 individuals in the combined hauls, with the exception of those shown in lighter shading which represent hauls of more than 250 but less than 500 individuals. The diagram does not include any stations in Weddell Sea water, since special conditions appear to exist in that area so far as this species is concerned.

A difference in the proportion of the catch taken in the upper and lower nets in summer and winter is immediately noticeable from the figure. This difference is most pronounced between the winter months, April and October 1932, and the summer months of the season 1932–3 (lower half of the figure), but is less clearly shown by the diagram for the summer months of the previous season 1931–2 (upper half of the figure).

During April 1932, in the South Indian Ocean, and October 1932, in the Drake

Passage, the greater proportion by far of the total catch at nearly all stations occurred in the lower nets. In the middle of the month of April 1932 there were three stations (850, 851 and 853) at which an almost equal proportion of the catch occurred in the upper and lower nets and another similar station (863) at the end of the month just south of

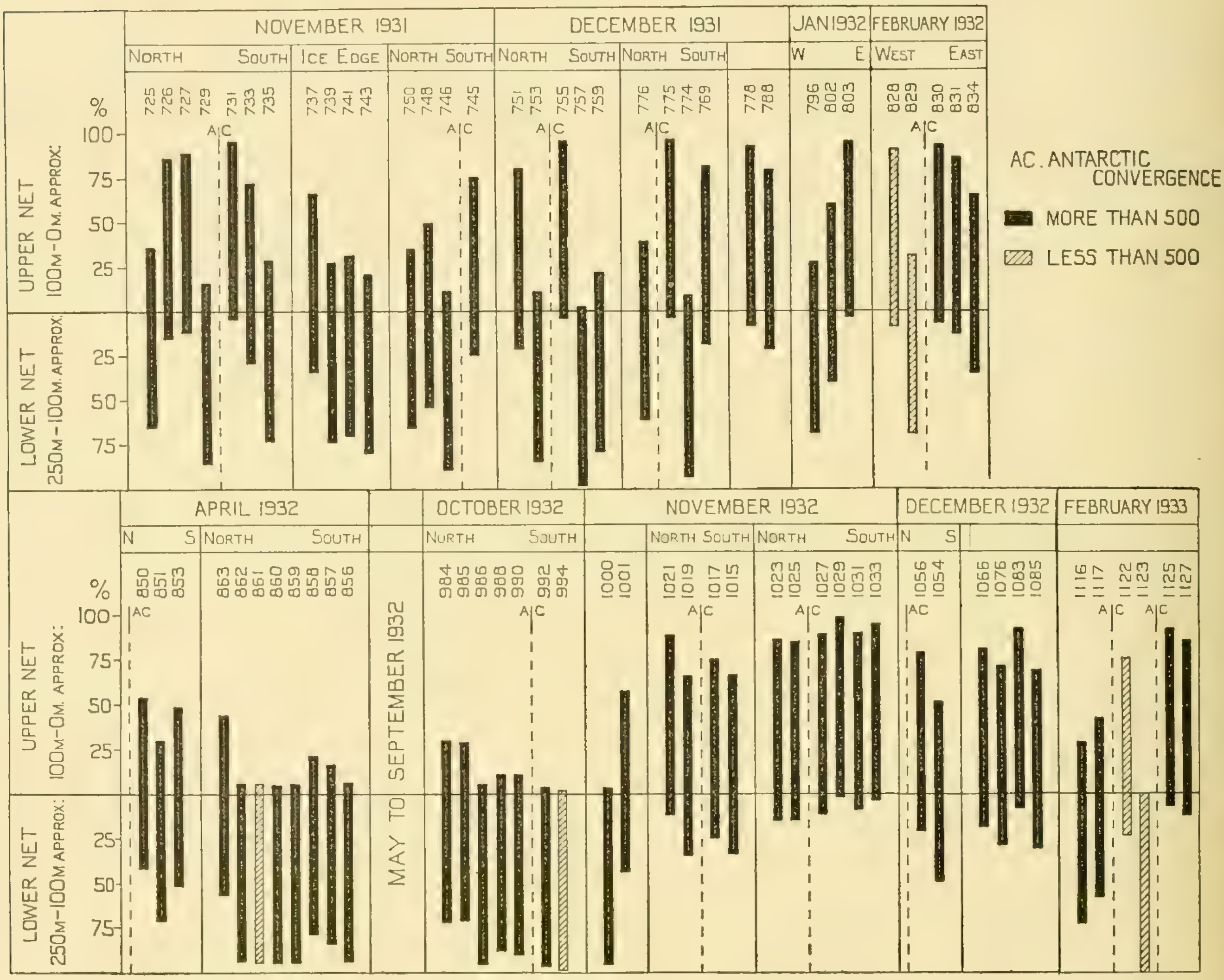

Fig. 12. Percentage of total catch of *Rhincalanus gigas* in upper and lower 1-m. nets, 1931–32–33. Falkland Sector (excluding stations in Weddell Sea water) and Indian Ocean Sector.

the convergence. At the six other stations taken during April almost the whole catch occurred in the lower nets. In November 1932, however, the greater proportion of the total catch was taken in the upper nets. The same condition was found throughout December and also in February 1933, although two stations in that month taken in the Drake Passage showed a majority in the lower nets, and at St. 1123, on the sub-Antarctic side of the convergence in February between the Falklands and South Georgia, the entire catch was in the lower nets. During the winter months the catches were mostly too small to give reliable percentages: during May and June, however, the catches were entirely or mainly in the lower nets (Table III *c*). There are no observations for

July or August 1932, but in September in the South Pacific Ocean *Rhincalanus* had practically disappeared from the catches.

It seems, then, that *R. gigas* spent the summer months November 1932 to at least February 1933 at the surface, mainly in the 100–0 m. layer. The progressive reduction of the catches during the winter months April–September 1932 in the West Wind Drift current around the Antarctic Continent, together with the descent of the catches from the upper to the lower nets in April, suggests that the species left the surface and descended into depths below 250 m. during the winter. During September 1932 it was out of range of the 250–100 m. net but came within its range in October 1932.

The same process appears to have taken place in the previous season, 1931–2, but the movements seem to be less clearly defined. In November of that season the larger proportion of the catches at most of the stations was in the lower nets. It is noticeable, however, that stations immediately south of the Antarctic convergence in the Drake Passage (Sts. 731, 733, 745) show a majority in the upper nets. During December in the western Scotia Sea and in South Atlantic water north and west of South Georgia the stations immediately south of the convergence (Sts. 755, 775 and 751, which was taken almost on the convergence) again show a majority in the upper nets, while those farther removed from the convergence (Sts. 753, 757, 759, and 774) show a majority in the lower nets. At three stations also during these months—Sts. 726, 737 and 769, which were taken in places where warm deep water wells upwards to the surface—a majority was also found in the upper nets. St. 726 is situated near the coast of South America, St. 737 near the continental shelf, and St. 769 on the ridge between the South Shetlands and the South Orkneys. At the few stations taken in the second half of December 1932 and in January and February 1933 the majority of the catch was in the upper nets.

Thus it appears that the rise of *Rhincalanus* to the surface in the season 1931–2 in Antarctic water away from the convergence took place in early December, nearly a month later in the year than in the following season 1932–3, when the rise to the surface occurred at the beginning of November. Deacon (1936) has found that the hydrological data show the season 1931–2 to have been colder and "later" (with respect to the southward movement of the isotherms) than the season 1932–3. The average temperature of the surface 50 m. of water in the region round South Georgia between 52 and 56° S and 33–40° W was 1·50° C. in the middle of January 1932 and 1·88° C. in the middle of January 1933. In 1931–2, however, the rise of *Rhincalanus* to the surface appears to have already taken place in November at stations near the convergence, so that it is possible that the spring ascent to the surface may take place earlier near the convergence than elsewhere. The precise conditions under which this ascent takes place are at present unknown, but it is perhaps to be expected that it will occur earlier near the convergence than elsewhere, since the warming effect of the approach of summer has been found (Deacon, 1936) to become marked sooner in the region just south of the convergence. It is permissible then to suggest that the spring ascent is connected with the attainment of a certain temperature by the water at the surface, and, indeed, that the whole

phenomenon of seasonal vertical migration is connected with temperature. Somme (1934) suggests that light intensity is also an important factor.

From the somewhat scanty data set forth above it seems possible to conclude that *Rhincalanus*, in the Bellingshausen Sea current and the Antarctic water of the West Wind Drift generally, undertakes a seasonal vertical migration similar to that established by Sømme (1934) for *Calanus finmarchicus* and *Calanus hyperboreus* in the northern hemisphere, spending the summer months November or December to about February at the surface and descending in April into the 250–100 m. layer and sinking still farther, below 250 m., at the beginning of May. It reappears in the 250–100 m. layer once more in October. Thus it follows that the winter months are passed in the warm deep water, in water of higher temperature and salinity, which is moving southwards and will therefore tend to carry the animal southwards. In the summer the species inhabits the northward-flowing Antarctic surface water, which will tend to carry it once more in a northward direction.

This theory of the seasonal vertical movements of *Rhincalanus gigas* receives confirmation from the work of the 'Discovery II' on her third commission (1933–5). Dr N. A. Mackintosh, under whose direction the work was carried out, has given a preliminary account of some of its more immediate results in *Nature* (1935). Part of the ship's programme during the seasons 1933–4 and 1934–5 involved the repetition at different times of the season of a line of plankton stations along the meridian of 80° W (western end of the Drake Passage). This line of stations was taken in December 1933 and March, September, October and November 1934. At each station a series of six vertical hauls was made, using the 70-cm. closing net, from various depths between 1000 m. and the surface. A preliminary examination of the samples obtained from these hauls reveals vertical movements on a large scale, not only of *R. gigas* but of several other macroplanktonic species. Mackintosh outlines the seasonal changes in the bathymetrical distribution of *Rhincalanus* as an illustration of these movements. In December the species was mainly concentrated at the surface above the 250-m. level, as was suggested by the hauls with 1-m. nets taken in 1931–2 and 1932–3. In March it tended to sink, larger catches being taken around the 500-m. level, especially north of the convergence. In September it was practically confined to the warm deep water below 500 m., but in October and November it regained the Antarctic surface water above 250 m.

Weddell Sea (Table IV *b*)

There are no observations extending over a long period by which to judge the seasonal vertical movements of *Rhincalanus* in the Weddell Sea, but stations were taken in this water in December and January 1931–2 and November, December, February and March in the season 1932–3. Fig. 13 shows the percentage of the total catch taken in the upper and lower nets at all the stations in Weddell Sea water during the two seasons and is constructed on the same plan as Fig. 12.

In December and January, in the season 1931–2, the majority of the catch was in the lower nets at all stations taken east of South Georgia in the oldest type of Weddell Sea

water—that is water flowing out of the Weddell Sea with an average temperature for the surface 100 m. between 0 and 1·0° C. (Sts. 779, 797, 798, 799, 806 and 808). At four other stations in colder water, at which the average temperature was between −1·0 and 0° C. (water in which ice has recently melted), that is at Sts. 795, 804, 807 and at 761, near the South Orkneys, the catch was likewise almost entirely in the lower nets. At all other stations in water flowing out of the Weddell Sea the catch occurred mainly or entirely in the upper nets.

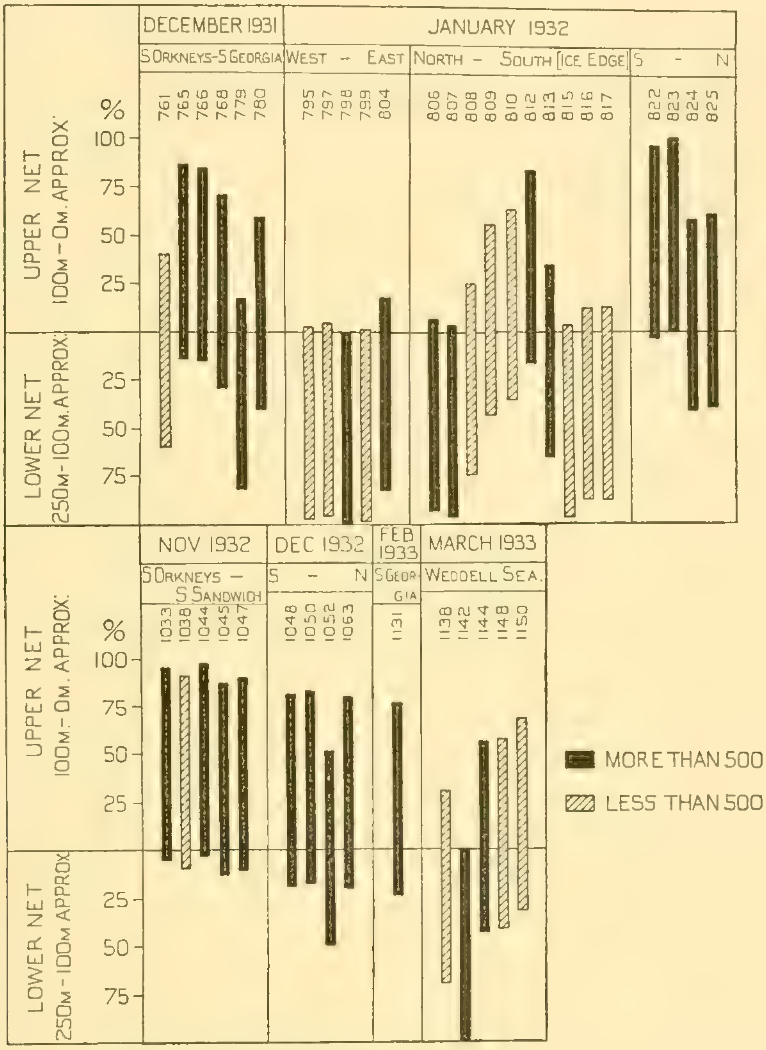

Fig. 13. Percentage of total catch of *Rhincalanus gigas* in upper and lower 1-m. nets, 1931–2 and 1932–3. Weddell Sea.

At the stations in the "oldest" type of Weddell Sea water (0–1·0° C.) east of South Georgia (Sts. 779, 797, 798, 799, 806), at which the catch was in the lower nets, it seems reasonable to assume that the *Rhincalanus* population originated from the South Atlantic and had been carried into water from the Weddell Sea by southward-moving warm deep water. At Sts. 795, 804, and perhaps 807, in Weddell Sea water carrying melting pack-ice, the origin of at least a part of the population is no doubt the same, and

at St. 761, near the South Orkneys, at least a part of the population will have been carried southward in warm deep water from the Scotia Sea. Since the population at these stations occurred almost entirely in the lower nets we may assume that it originated outside the Weddell Sea in the Scotia Sea or South Atlantic. At nearly all the other stations in water flowing out of the Weddell Sea the population must belong to the stock of *Rhincalanus* in the Weddell Sea itself (Sts. 765, 766, 768, 780, 809, 812, 822–5). At Sts. 765, 766 and 768, however, it may be expected that a large proportion of the population sampled by the upper nets originated in the Drake Passage, since in this area there is a large degree of mixing of the waters of the Bellingshausen Sea and Weddell Sea currents. At all these stations the catch appeared in the upper nets. Sts. 815, 816 and 817 were taken in the current that flows westwards into the Weddell Sea along the coast of Coats Land south of 66° S. At these stations the catch was in the lower nets. At St. 813, at which there was a small majority in the lower nets, part at least of the population belongs to the westward-flowing current, since this station lay on the boundary between water flowing westwards into the Weddell Sea and that flowing eastwards out of it. The deeper layers of this water, as already explained (p. 282), originate in warm deep water in the South Indian Ocean, so that it seems that *Rhincalanus* enters the Weddell Sea either from the South Atlantic in warm deep water or from the Indian Ocean in the warm deep current that flows westwards into the Weddell Sea south of 66° S. Deacon (1936) found Atlantic water as far south as Sts. 806 and 808, but at St. 807 and the other stations farther south the deep water was found to originate mainly from the current flowing westward into the Weddell Sea south of 66° S. In water flowing out of the Weddell Sea, however, *Rhincalanus* apparently rises to the surface, since at nearly all the stations in the Weddell Sea north-easterly current, except those in the very "oldest" water, the catches were in the upper nets. A hydrological explanation of this is available in the case of certain stations in the centre of the Weddell Sea cyclonic system (Sts. 809, 812, 813, 822 and 823). These stations lay in an area intermediate between the westward current flowing into the Weddell Sea and the water flowing north-eastwards out of it. In this area, as Deacon shows in work now in the press (1936), there is an upwelling of warm deep water towards the surface in the deeper layers. Although the isotherms within the surface 250 m. give no clear indication of upwelling it may exist to a small extent in the upper layers and may still influence the plankton above the 250-m. level. At the stations in water flowing out of the Weddell Sea to the west near South Georgia (Sts. 765, 766, 768, 780 and 825) a large part of the population very probably belongs to the Bellingshausen Sea water, which here mingles with water from the Weddell Sea.

It seems necessary to bear in mind, when considering these questions of the vertical distribution of the plankton, that variations in the level of concentration are not brought about so much through the conveyance of plankton from one level to another by the movements of masses of water as through the active migration of the plankton along temperature gradients to levels where an optimum temperature occurs. For instance, the upwelling of warm water in the centre of the Weddell Sea, above mentioned, in-

volves no marked upward movement of a mass of water such as could carry the plankton to the surface, but it does effect a raising of the level at which the temperature, or some other factor, is an optimum and might thus bring about the active concentration of the plankton at that level.

In the season 1932–3, during November and December, at all the stations in Weddell Sea water, except St. 1052 which was taken in Weddell Sea water of the "oldest" type, the majority of the catch was in the upper nets. At St. 1052 there was an approximately equal proportion in the upper and lower hauls. Thus, as in the previous season, the population of *Rhincalanus* in the "younger" water flowing out of the Weddell Sea (water colder than 0° C.) belongs to the Weddell Sea stock and was found at the surface, while the population at the only station taken in the "oldest" type of Weddell Sea water (water between 0 and 1·0° C.) was found largely in the lower haul and part of it at any rate must have come from farther north in warm deep water. On the line into the Weddell Sea taken during March 1933, Sts. 1138, 1142 and 1144 were taken in water flowing north-eastwards out of the Weddell Sea (Fig. 2*b*), while Sts. 1148 and 1150 were taken in water flowing westwards into the Weddell Sea. At St. 1142 the entire catch of over a thousand individuals occurred in the lower net. This station, as the 100-m. temperature indicates, was taken in a tongue of warmer water possibly moving southwards from the South Atlantic. The *Rhincalanus* population here is probably, therefore, of definitely South Atlantic origin, carried southwards in warm deep water. At St. 1138, at which most of the catch was in the lower nets, part at least of the population belongs to the warm deep water and part to the Weddell Sea itself, since this station was taken near the boundary between the Bellingshausen and the Weddell Sea currents.

At Sts. 1148 and 1150, in water flowing westwards into the Weddell Sea, the majority of the catch was in the upper hauls, although the proportion in the lower nets was high. At the stations taken in this water in January of the previous season (Sts. 816 and 817) the majority of the catch was in the lower nets and it was assumed that the population which enters the Weddell Sea in this current originates from the warm deep water of the South Indian Ocean. If we compare these two stations with Sts. 1148 and 1150 it is noticeable that the discontinuity which marks the upper limit of the westward-flowing deep water lies between 70 and 80 m. at St. 1150 (Table II*b*), while St. 1148 lies on the boundary between the westward- and eastward-flowing water, where, as already explained, warm water wells upwards in the lower layers. At Sts. 816 and 817, on the other hand, the discontinuity is found at a depth of about 150 m. (Table II*a*). This might well account for the fact that a comparatively high proportion of the catch of *Rhincalanus* was taken in the upper nets at Sts. 1148 and 1150, but in the lower at Sts. 816 and 817.

On the evidence available it is not possible to generalize much about the vertical distribution of *Rhincalanus* in the Weddell Sea. It will be shown later that the population in this area is probably not endemic (pp. 330–2) and must originate from waters outside the Weddell Sea area. From the foregoing account of the vertical distribution it may be said that the population of the Weddell Sea is derived from two sources—from the current

flowing westwards into the bight south of 66° S and known as the East Wind Drift current and from the South Atlantic warm deep water. The main body of the population, as sampled in the colder water carrying ice, is probably carried into the Weddell Sea in the East Wind Drift, but where water from the Weddell Sea meets with warmer water from the Bellingshausen Sea, north of the Scotia Arc and farther east as far south as St. 808, a sparse population is found which owes its origin to Atlantic warm deep water. The population in the East Wind Drift flowing into the Weddell Sea, in its turn, originates in warm deep water in the South Indian Ocean. It appears to rise to the surface before leaving the Weddell Sea in the north-easterly current and this, at least partly, may be due to the upwelling of warm water which takes place in the centre of the circular Weddell Sea current system and along the divergence region between the two water movements which make up that system.

These conclusions are largely in agreement with those of Ottestad (1932), who has already suggested that the stock of *Rhincalanus* in these waters belongs not properly to the Weddell Sea but to waters outside that area and is carried into it by southward-moving water from the South Atlantic.

HORIZONTAL DISTRIBUTION, SEASON 1932–3

Falkland Sector, October to December (Table III *b*)

The lines of equal distribution of *R. gigas* for the first half of the season 1932–3 (Figs. 14, 15) show certain differences from those for the season 1931–2. The area of maximum abundance is greatly reduced, and only at two stations (1017 and 1025), between the Falklands and South Georgia, did the catch in the combined nets exceed 10,000 individuals. The line of stations at the western end of the Drake Passage was taken during the last week in October, over a month earlier in the year than in the previous season. As we have seen (pp. 301–3) the spring ascent to the surface from the winter level of the species was not yet completed at that time. The comparatively small numbers taken on this line may therefore be attributed to the fact that *Rhincalanus* had not yet completed its ascent into the range of the 250–100 and 100–0 m. nets when the line was taken.

In the spring of 1932–3 the Bransfield Strait was found to be clear of pack-ice, the edge of which lay farther south in the Bellingshausen Sea than at the same time of year in the previous season. The most southerly station—St. 735, on the Western Drake Passage line in November 1931—lay in 63° 55′ S and 73° 28·8′ W (Fig. 1 *a*), while at the end of October 1932 the most southerly station, at the edge of the pack-ice, was taken in 66° 45·7′ S and 80° 19·8′ W (St. 994, Fig. 2 *a*). In October 1932 and early November the edge of the ice was followed into the Bransfield Strait to Deception Island and finally as far as the longitude of Joinville Island (Fig. 2 *a*). *R. gigas*, and indeed the Copepoda generally, were found to be practically absent from the Bransfield Strait and from the coldest Bellingshausen Sea water (with a temperature lower than − 1·5° C., carrying unmelted pack-ice). The plankton as a whole in this area was extremely poor.

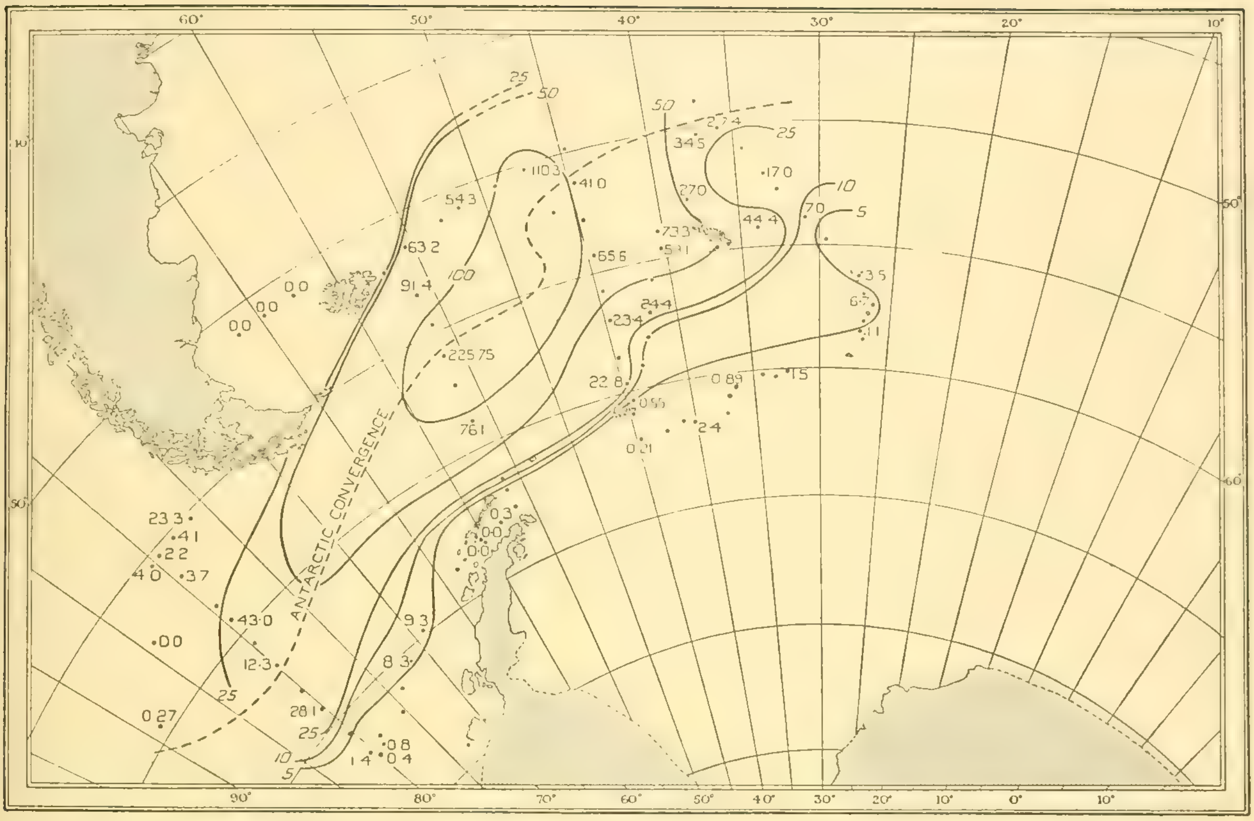

Fig. 14. Horizontal distribution of *Rhincalanus gigas* in the Falkland Sector of the Antarctic, October to December 1932. (1-m. nets, 250–100 m. approx., 100–0 m. approx., both hauls combined.) Numbers represent hundreds of individuals.

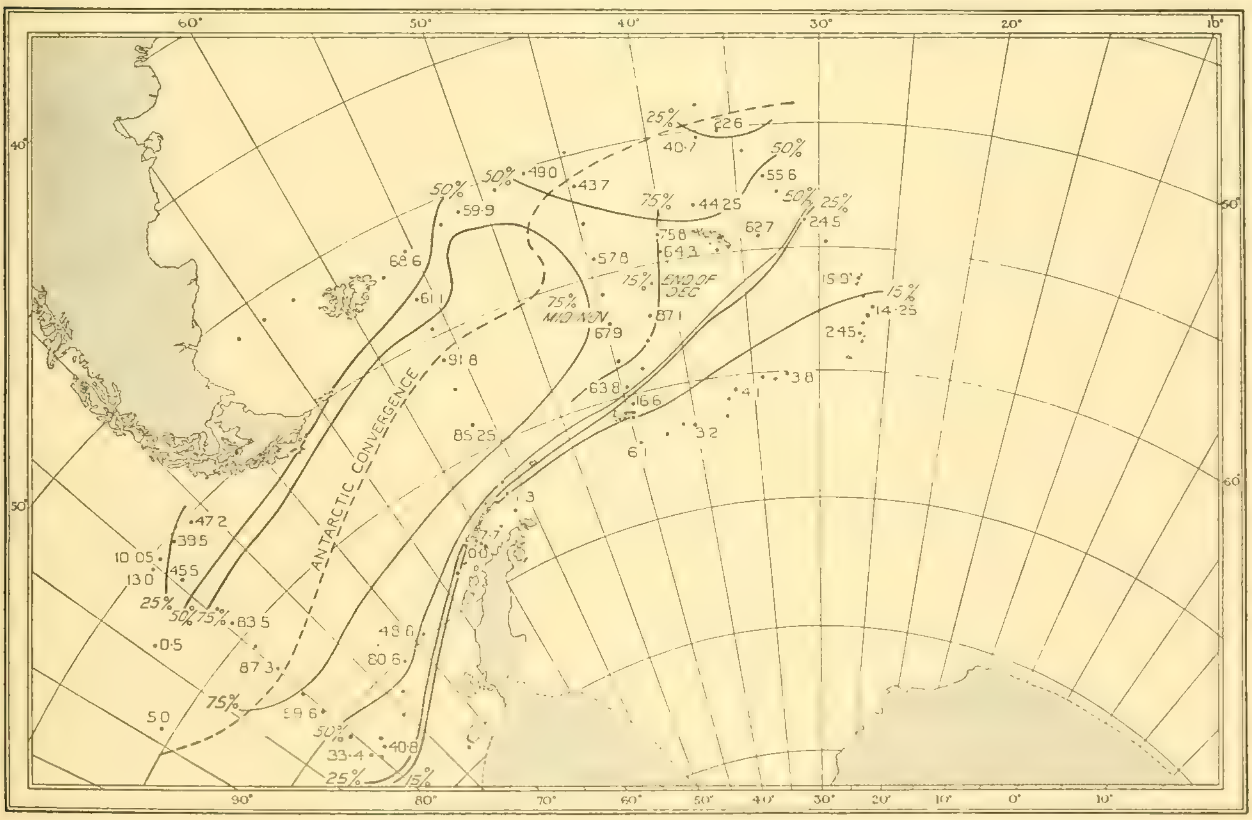

Fig. 15. Percentage distribution of *Rhincalanus gigas* in the Falkland Sector of the Antarctic, October to December 1932. (1-m. nets, 250–100 m. approx., 100–0 m. approx.) Numbers represent percentage of *R. gigas* in total copepod catch in the upper and lower hauls together.

At two stations, however, situated somewhat to the north at the western entrance to the Bransfield Strait (Sts. 1000 and 1001) an appreciable catch was taken. Here the catches amounted to 425 and 931 individuals respectively. These two stations lay near the Antarctic continental shelf, where, as already explained, there is upwelling of warm deep water towards the surface, and it may be that at these two stations the *Rhincalanus* population is carried upwards from its winter level by upwelling warm deep water as was found at the stations in the Southern Drake Passage in the previous season.

The area of abundance of *R. gigas* (more than 5000 individuals) during the period from late October to the end of December 1932 was again found in the Drake Passage and the western Scotia Sea (Fig. 14). It occupied that part of the West Wind Drift and Bellingshausen Sea currents in the Drake Passage and between South Georgia and the Falkland Islands. South of the Falklands it embraced all stations at which the average 0–100-m. temperature was higher than – 1·0° C. and lower than 5·0° C. and included stations in the sub-Antarctic zone between the Falklands and South Georgia, and in sub-Antarctic water in the western Drake Passage. In the preceding season the 5000 line included stations in the sub-Antarctic zone between the Falklands and South Georgia, but none in the western Drake Passage where the 3° isotherm formed the northern boundary of both the 5000 and 10,000 regions of abundance. It thus does not include Bellingshausen Sea water carrying melting or unmelted pack-ice. In the eastern part of the area of abundance, south-west of South Georgia, the 0° isotherm forms the approximate southern boundary of the region where the catches exceed 2500 individuals.

The stations in the Weddell Sea water east of South Georgia and in the Scotia Sea were taken at the end of November and beginning of December, about a week earlier in the year than the stations in the corresponding position in the previous season (Sts. 761–8). The same comparative scarcity of *Rhincalanus* can be seen in the colder Weddell Sea water carrying pack-ice (colder than 0° C.) in the season 1932–3 as in the previous year. At only one station (1047) in Weddell Sea water colder than 0° C. was the catch in both nets together in excess of 500 individuals. At nearly all of them it was less than 250 individuals. East of South Georgia there is a tongue of Weddell Sea water running northwards and westwards (Fig. 6) similar to that observed in 1931–2. The lines of equal distribution of *Rhincalanus* likewise take a similar bend to the west and north before turning east across the South Atlantic. There is also a spreading out of the lines of equal distribution in the Scotia Sea south of South Georgia, where the influence of the Weddell Sea and Bellingshausen Sea currents mingle.

It is seen from the above that the stations which correspond in date and position in the two seasons (those around South Georgia and in the Scotia Sea) do not show marked differences in the distribution of *R. gigas*, so that it is perhaps justifiable to attribute those differences in distribution which do appear in the Drake Passage to the earlier date of the stations in these waters in 1932–3 than in 1931–2. They were taken before the spring ascent to the surface had been completed in the former season but after its completion in the latter.

Falkland Sector, February to March (Table III *b*)

The line of stations from the South Shetlands to the Falklands taken in early February (Sts. 1115, 1116, 1117 and 1119) shows a striking reduction in numbers in this region compared with the conditions at the beginning of November (Fig. 16). At Sts. 1116 and 1117 the catches in the two nets combined amounted to 2860 and 2416 individuals respectively, compared with catches in November of over 5000 and, at St. 1017, of over 10,000 (Fig. 14). At St. 1119, north of the convergence, only 80 individuals were taken in the two nets together.

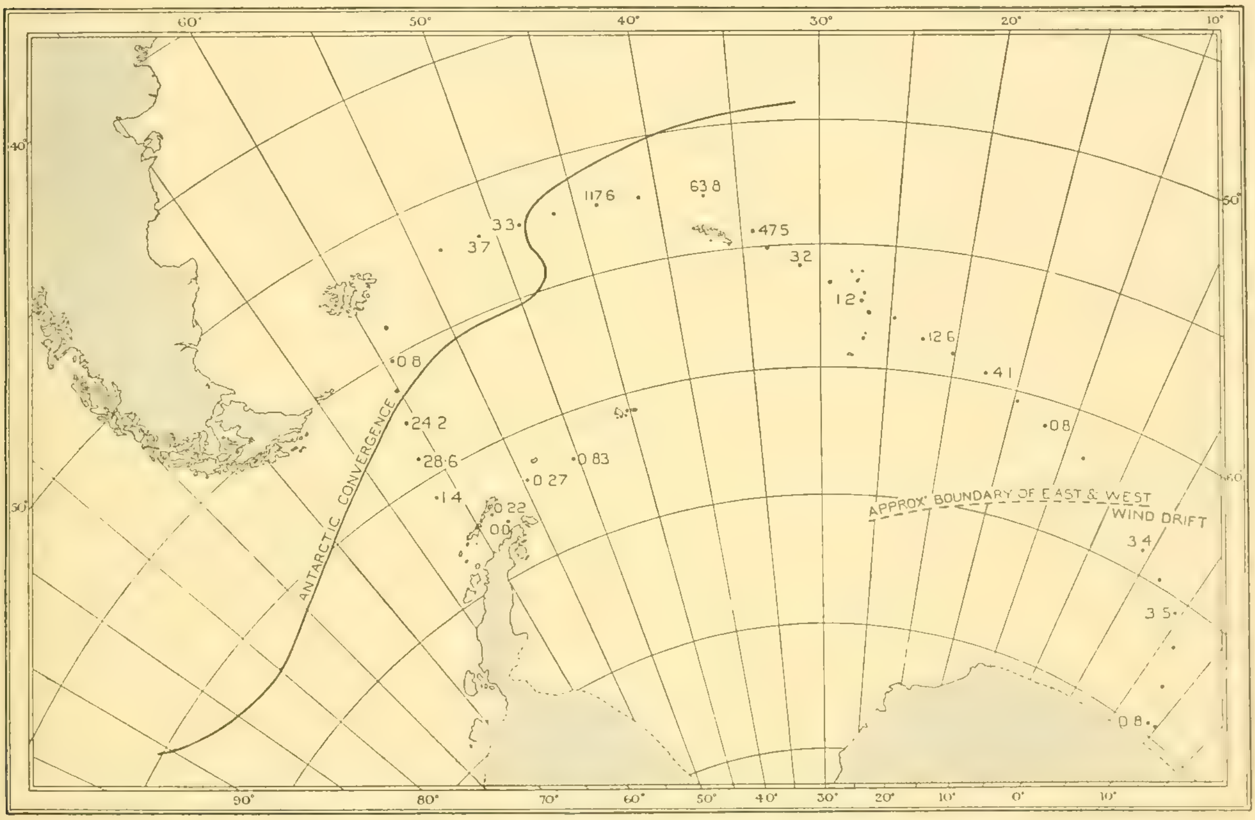

Fig. 16. Horizontal distribution of *Rhincalanus gigas* in the Falkland Sector of the Antarctic, February to March 1933. (1-m. nets, 250–100 m. approx., 100–0 m. approx.) Numbers represent hundreds of individuals.

On the line between the Falkland Islands and South Georgia at the end of February (Fig. 16) we find conditions closely resembling those found in this area in the February of the preceding season (Fig. 10). At the three stations in Antarctic water the catches were very large and amounted to more than 10,000 individuals at the more westerly (St. 1125) and more than 5000 at the more easterly, near South Georgia (St. 1127). At St. 1131, at the eastern end of the island, the catch amounted to more than 2500 individuals. At Sts. 1122 and 1123, however, in sub-Antarctic water, the catches of *Rhincalanus* were small and did not exceed 500 individuals—370 and 328 respectively. These two stations and St. 1119, south of the Falklands, therefore, again show the

restriction of *Rhincalanus* to Antarctic water at the end of the season which we have already noticed (pp. 298–9). It may be regarded as the winter condition and as a regularly occurring process.

The line between the South Shetlands and the Falklands also shows a feature to which Mackintosh (1934, p. 121) has already drawn attention. This is the sharp division between the moderately rich catches at the two northerly Antarctic Stations (1116 and 1117) and the comparatively very poor catch at the most southerly station (1115). Mackintosh has already shown that this line of demarcation can be drawn in the southern Drake Passage for the plankton as a whole, and from comparisons of its positions at different dates in different years he suggested that the line moves southward during the season. At the beginning of the season 1932–3, at the end of October and beginning of November, there was a similar line of demarcation so far as the distribution of *R. gigas* is concerned between Sts. 992 and 994 and between Sts. 1014 and 1015 (Fig. 14), but these stations are too far apart for the exact position of the line to be fixed. Its position in February between Sts. 1115 and 1116 does not, however, suggest that it has moved appreciably between the beginning and the end of the season. Mackintosh (1934, p. 121) further suggested that there is a rich plankton in the central part of the Drake Passage which spreads farther southwards towards the end of the summer. We have seen, however, that so far as *R. gigas* is concerned, there is a diminution in quantity towards the end of the summer in the Drake Passage, and the largest catches on the February line, taken at Sts. 1116 and 1117, do not suggest any marked southward movement of the area of abundance. In fact the indications are that the area of abundance moves away northeastwards towards South Georgia—as indeed one might expect in view of the general direction of flow of the surface waters. Thus, while reduction in numbers takes place in the Drake Passage, the species still remains fairly abundant around South Georgia (Sts. 1125 and 1127) at the end of the summer.

The line from South Georgia to the pack-ice edge in 69° 22′ S, 9° 37·5′ E, taken in March, passes throughout its length through Weddell Sea water. As already explained the western stations on this line (Sts. 1138–47; Fig. 2*b*) were taken in water flowing northeastwards out of the Weddell Sea, while the more easterly stations (1148–53) were taken in the East Wind Drift current flowing westwards into the Weddell Sea. St. 1148 lies in the area of divergence between these two masses of water. At St. 1142, as already explained (p. 307), there appears to be a tongue of warmer water moving southwards, since at this station the average temperature between 0 and 100 m. is above 1·0° C. (Fig. 7), while at all the stations south of it it is less than 0° C. All the catches on this line were small, less than 500 individuals, as is usual in Weddell Sea water, except at the warmer station (1142) at which over 1000 individuals were taken. This station corresponds in position with St. 807 (Fig. 1*a*), taken in mid-January in the preceding season. The catch in the two hauls combined at that station was 520 individuals. In January 1932, however, the southward movement of warm water in this area was less pronounced than in March 1933 and extended only to St. 806 at which 1104 individuals were taken.

Fig. 15 shows the distribution of *R. gigas* based on its percentage of the copepods in

the catches. It is again evident that while the Drake Passage was an area where *R. gigas* was the most important species of copepod in the fauna (75 per cent and over), the Weddell Sea was an area where it made up only a small proportion of the fauna. At the stations in the South Sandwich–South Georgia area with a temperature lower than 0° C. it comprised less than 25 °/₀ of the total Copepoda and at all stations with a temperature less than $-1{\cdot}0°$ C. less than 15 per cent of the total. It will be seen immediately that there is a striking difference between the percentage distribution (Fig. 15) and the numerical distribution (Fig. 14). In the season 1931–2 the two figures for the numerical and the percentage distribution (Figs. 8, 9) resemble one another fairly closely. Throughout the whole of its area of maximum abundance in that year (catches of more than 10,000 individuals) *R. gigas* was the dominant species of copepod, forming 75–100 per cent of the total copepod catch. In the season 1932–3 *R. gigas* was the dominant species of copepod in the Drake Passage (Fig. 15), but farther east between the Falklands and South Georgia it formed only 50–75 per cent of the catch at several stations where more than 5000 individuals were taken in the two hauls together. At St. 1025, where more than 10,000 individuals were taken, it formed less than 50 per cent of the catch. It is evident that in the northern and eastern part of the area of abundance in the season 1932–3 species of copepod other than *R. gigas* were present in larger proportions in the catches than at corresponding stations in the preceding season. Thus at Sts. 1019, 1023, 1025 and 1029, between the Falklands and South Georgia (Figs. 2*a*, 15), species other than *R. gigas* formed between 25 and 50 per cent of the copepod fauna, while at Sts. 750, 751 and 788, which are as nearly as possible the corresponding stations in the previous season (Figs. 1*a*, 9), species other than *R. gigas* formed less than 25 per cent of the copepod fauna. Similarly, at the beginning of December, north of South Georgia at Sts. 1054, 1056 and 1063 (Figs. 2*a*, 15), the species was a somewhat less important constituent of the copepod plankton than in this locality at the same time in the previous season. At Sts. 1054, 1056 and 1063 it formed less than 50 per cent of the total copepod catch, but in 1931–2 at St. 774 it formed more than 75 per cent and at St. 775 about 50 per cent of the catch. It is not proposed here to deal with the distribution of other species of Antarctic copepods, but it may perhaps be mentioned that at Sts. 1019 and 1023, near the Falklands, the proportion of warm-water species, characteristic of the sub-Antarctic zone, was higher than in the same region in the preceding season (Sts. 750 and 751). Conversely, at St. 1029 (Fig. 2*a*) the proportion of cold-water species, characteristic of the colder waters of the Weddell Sea, was higher than at St. 788, which corresponds in position with St. 1029, in December 1931. There is a difference in date between Sts. 1019 and 750 of three weeks (9. xi. 32 and 30. xi. 31), between Sts. 1023 and 751 of about a fortnight (16. xi. 32 and 1. xii. 31) and between Sts. 1029 and 788 of over a month (19. xi. 32 and 21. xii. 31). The higher proportion of warm-water species between the Falklands and South Georgia in mid-November 1932 (Sts. 1019, 1023 and 1025), in contrast with that at the end of November and the beginning of December 1931 (Sts. 750 and 751), may probably be correlated with the more southerly position of the isotherms in 1932–3 than in 1931–2 (Figs. 5, 6). As we have already seen (p. 303) Deacon found the season 1931–2 to have been colder and "later"

than the season 1932–3, and this has been suggested as a possible explanation of the late ascent of *Rhincalanus* to the surface in the former season. We now see that this same cause may account for the difference in the composition of the copepod fauna generally at the beginning of the second season of the commission. The higher proportion of cold-water Weddell Sea species at St. 1029, however, may be accounted for by the fact that St. 1029 was taken in the tongue of Weddell Sea water which pushes northwards west of South Georgia towards the Falklands (Fig. 6), while St. 788, in December 1931, was taken in the Bellingshausen Sea current. St. 1066, taken in the middle of December 1932 near the western end of South Georgia, and the three stations, 1083, 1085 and 1088 (Fig. 2*a*), taken at the end of that month between South Georgia and the South Orkneys, seem to show that the proportion of *R. gigas* increased in the copepod fauna towards mid-summer in the region west and south-west of South Georgia. This is indicated in Fig. 15 by a repetition, farther east, of the 75 per cent line. A comparison of the isotherm charts for the first and second halves of the season 1932–3 (Figs. 6, 7) reveals a southward and eastward movement of the isotherm lines in this region which would, no doubt, be responsible for an increase in the proportion of *R. gigas* in the fauna and a corresponding reduction in the proportion of cold water species characteristic of the Weddell Sea.

VERTICAL RANGE AND DIURNAL VARIATION

There is no evidence from the hauls under consideration as to the depths below the 250-m. line to which *Rhincalanus* may extend. Hardy and Gunther (1935, p. 141), however, write of this species during the summer months: "It was most abundant between 50 and 250 m. and was not taken at levels below 750 m." We have seen, however, that the area of abundance of the species almost certainly descends below 250 m. during the winter, and Mackintosh (1935) has shown that the winter level of the species lies between 500 and 1000 m. Schmaus and Lehnhofer (1927, table *c*) record the species in a vertical haul in the South Indian Ocean between 1900 and 2500 m.[1]

The hauls which form the subject of this paper were taken in a great many different places and at a great many different times and do not provide evidence as to the vertical diurnal movements of *R. gigas*. Hardy and Gunther (1935, p. 241, fig. 109) have, how-

[1] Since the above was written a series of hauls was taken with the 70 cm. silk net towed obliquely at various depths at several stations along the ice edge south of the Indian Ocean during November and December 1935. The catches of *Rhincalanus gigas* taken in these hauls are tabulated below.

St.	Date 1935	Depth m.	Latitude	Longitude	No. of *R. gigas*
1642	3. xii	158–0	58° 55·3′ S.	95° 49·0′ E.	1524
1636	30. xi	380–150	57° 49·2′ S.	84° 23·9′ E.	312
1627	26. xi	580–400	57° 55·6′ S.	61° 49·8′ E.	480
1633	29. xi	1100–875	56° 35·7′ S.	70° 07·8′ E.	268
1639	2. xii	2400–1150	58° 35·0′ S.	92° 06·2′ E.	211

ever, shown that *R. gigas* exhibits no diurnal vertical migration, but that there seems to be a tendency for the species to occur at a higher level during the afternoon towards the end of the hours of daylight (p. 242, fig. 112).

SUMMARY

1. The area of greatest abundance of *R. gigas*, in which the species was most abundant both numerically and proportionately, in the Falkland Sector during the summer seasons 1931–2 and 1932–3, lay in the Drake Passage and in the South Atlantic Ocean. In 1931–2 it occupied the Bellingshausen Sea current south of the Antarctic convergence, but in 1932–3 it extended north of the convergence into sub-Antarctic water in the Drake Passage and between the Falklands and South Georgia (pp. 294, 310).

2. This area of abundance is in striking contrast with the comparative scarcity of the species in the Weddell Sea current (pp. 296, 297).

3. In the South Atlantic the limits of the area of greatest abundance were the Antarctic convergence on the north and the 0° C. isotherm, calculated from the average temperature of the surface 100 m., on the south. In the Scotia Sea, where the influences of the Bellingshausen Sea and Weddell Sea currents mingle, the southern limit of the area of abundance was less certainly fixed, but lay somewhere between the 0 and 1·0° isotherms. In the Drake Passage the southern limit of the area of abundance was not defined in the season 1931–2. There was a great abundance of the species in water colder than − 1·5° C., which was perhaps due to the upwelling of warm deep water along the Antarctic continental shelf. In the season 1932–3 the northern limit of the area of abundance was not strictly defined in the Drake Passage and South Atlantic but seems to have been more or less coincident with the 5·0° isotherm. The southern limit in the Drake Passage was the − 1·0° C. isotherm (pp. 294, 310).

4. The species occurred in fair abundance at the stations taken in sub-Antarctic water in the South Atlantic during both seasons. At the end of both seasons, however, it became restricted to the Antarctic Zone, and was taken in very small numbers in sub-Antarctic water (pp. 298, 311, 312).

5. In the winter months around the Antarctic Continent a progressive diminution of the catches in the surface 250 m. was found, together with the restriction of the species to the Antarctic Zone. By mid-winter *R. gigas* had almost disappeared from the catches, and in September in the South Pacific it had disappeared completely. Observations for July and August are lacking. The species reappeared in the surface 250 m. in October in the western Drake Passage (pp. 299, 301).

6. A study of the proportion of the combined catches taken in the upper and lower nets strongly suggests that *R. gigas* spends the summer months within the surface 100 m. and descends in about April to a level between 250 and 100 m., while in May it sinks below the 250-m. line and remains there until October, when it reappears between 250 and 100 m. In November it regains the surface. Thus this species undertakes seasonal vertical migrations similar to those found for several species in the northern hemisphere. Its habitat during the summer months is thus the northward-flowing Antarctic surface water and during the winter months the southward-flowing warm deep water (pp. 301–2).

7. Certain differences in the distribution of the species in 1932–3 from the distribution in 1931–2, such as the scarcity of the species in the western Drake Passage in October 1932, have been ascribed to the fact that the investigations were carried out a month earlier in the spring of 1932–3 than in the spring of 1931–2, before the spring ascent of the species had been completed. Otherwise the differences in distribution during the two seasons were not very great. The catches generally were smaller in 1932–3 than in 1931–2 (pp. 308–11).

8. As the season advances there is, so far as can be ascertained, a general diminution in the catches of *R. gigas*, with a tendency for the area of maximum abundance to become concentrated in Antarctic water around South Georgia rather than in the Drake Passage (p. 312).

9. The comparatively small *Rhincalanus* population in the Weddell Sea enters that area by means of the southward-flowing warm deep water from the South Atlantic or South Indian Oceans. In the latter case it is carried into the Weddell Sea in the deep water of the East Wind Drift current flowing westwards into the Weddell Sea south of 66° S along the coast of Coats Land (pp. 304–7).

10. The species appears to be carried upwards to the surface out of the deep water by some unknown factor in the course of its passage around the Weddell Sea. It is suggested that the upwelling of warm water in the centre of the cyclonic system may perhaps be the cause of this (p. 306).

LIFE HISTORY

APPROACH OF THE SPAWNING PERIOD

The indications of the approach of the spawning period in any copepod population are:

(1) The appearance of large numbers of females with ripe gonads.

(2) The appearance of male adults in large numbers in the catches.

(3) The approach of the stock to maturity as indicated by the disappearance of juveniles from the population.

These indications may be discussed separately.

Appearance of ripe females. No detailed observations of the numbers of ripe females in the catches were made during the season 1931–2. During the season 1932–3, however, a selection of samples of 50 or less adult females from a number of stations was preserved and examined for the presence of ripening eggs in the gonads. The samples selected cover the period from the end of October to the middle of March, but owing to the fact that the ship was engaged on hydrographic survey during January there are no observations for that month.

R. gigas is transparent and in the female the gonads can be clearly seen occupying a saddle-shaped area postero-dorsally beneath the carapace (Fig. 17). Two long oviducts run back from the ovary on either side to open on the genital segment. In the yet immature female the genital cells are transparent and almost invisible in the dorsal and

posterior part of the saddle-shaped ovary. The oviducts appear as a fine cord of transparent cells on either side of the body (Fig. 17 *a*). As maturity approaches the anterior and ventral border of the saddle-shaped ovary takes on a deep brown colour in the preserved specimen and can be seen to be made up of a line of large dark cells each with a circular nucleus (Fig. 17 *b*). This border of enlarged cells, the young eggs, extends from the most anterior part of the ovary under the carapace along the ventro-lateral margin of the gonad and oviducts to the genital opening. The ripening eggs become larger and

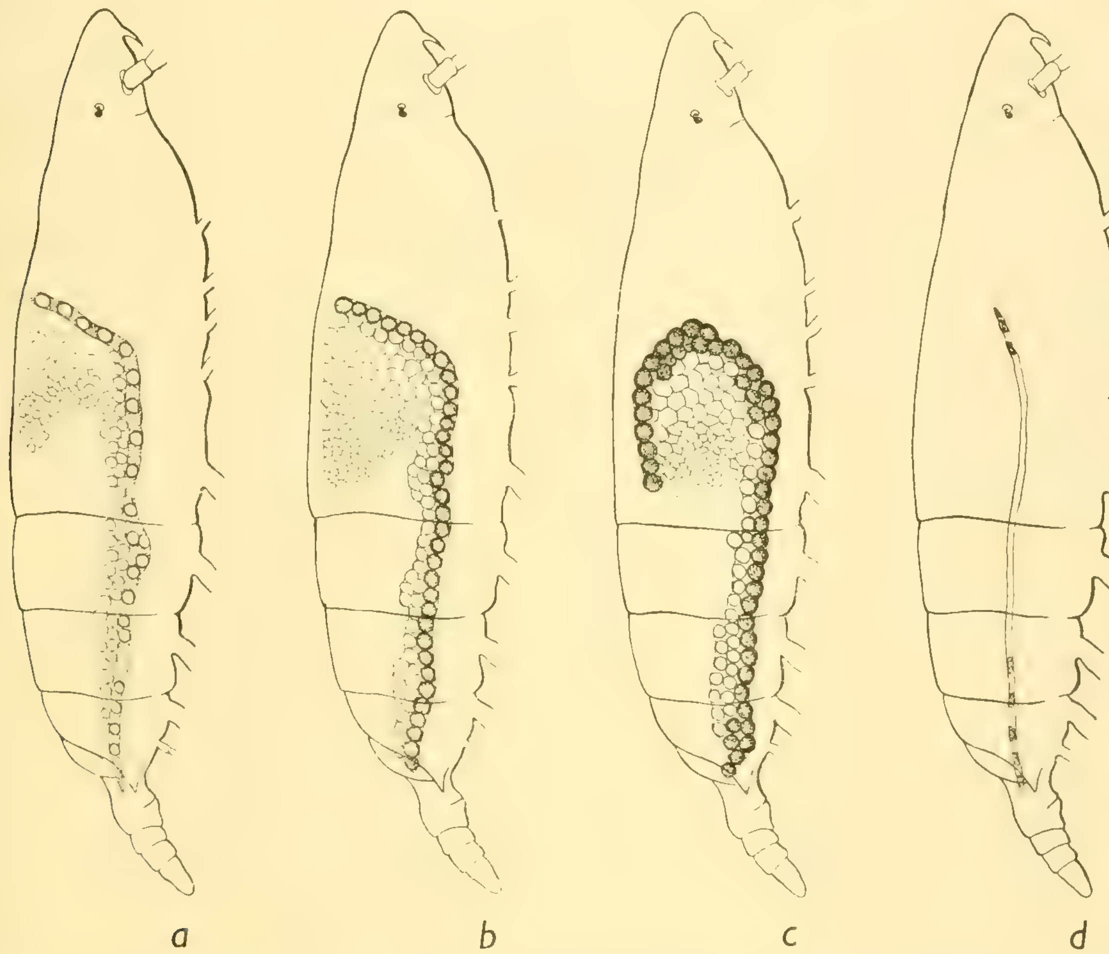

Fig. 17. *Rhincalanus gigas.* Adult females. Condition of the ovaries. *a*. Unripe. *b*. Maturing. *c*. Ripe. *d*. Spent

darker as maturity approaches, and, when about to be shed, they appear as very large dark circular, discrete cells, resembling a string of beads, forming a conspicuous row along each side of the thorax from the most anterior part of the ovary in the centre of the carapace to the genital opening (Fig. 17 *c*). Towards the end of the season many females appeared in the samples in which the only sign of a gonad was a thin transparent string of tissue on either side of the posterior segments of the thorax (Fig. 17 *d*). No cell limits were distinguishable in this, and it was assumed that these were "spent" females which had shed their eggs.

It was found impossible to do more than draw up a very rough classification of the females examined. No very definite distinction could be made between unripe females, in which the gonads were transparent, and maturing females, in which the ripening eggs could be detected as a dark border to the gonad. This dark border appears first as a line along the margin of the gonad only less transparent than the gonad itself. Similarly it was very often difficult to distinguish between maturing females in which the eggs were almost ready to be shed and ripe females in which the eggs were evidently fully ready to be shed. Four classes, then, of adult females have been very roughly distinguished: namely, unripe females, maturing females, ripe females and spent females. It is possible, however, that among the "unripe females" are some in which the incipient dark border of ripening eggs could be seen, while the class "maturing females" is a very indefinite one and includes all those in which the eggs form a dark border to the gonad. It may, therefore, include many ripe females. Similarly, the class "ripe females" may include many very nearly mature specimens in which the large bead-like eggs could be seen in the oviducts but were not really ready to shed.

The numbers of each of these four classes of adult females found in each sample examined have been tabulated below together with the percentage of each class in the total sample. The number of females examined was 50 in most instances, but it will be seen that at several stations, at which the major part of the catch consisted of juveniles, considerably less than 50 females were examined.

Degree of maturity of adult females of Rhincalanus gigas, *October* 1932 *to March* 1933

Date	St.	Depth m.	No. examined	Unripe		Maturing		Ripe		Spent	
				No.	%	No.	%	No.	%	No.	%
1932											
24. x	984	240–100	46	20	80	5	20	—	—	—	—
26. x	988	88–0	60	29	48·3	26	43·3	5	8·3	—	—
		224– 74	50	13	26	33	66	4	8	—	—
27. x	990	276–100	50	37	74	13	26	—	—	—	—
28. x	992	270–110	50	20	40	30	60	—	—	—	—
1. xi	1000	300–110	50	47	94	3	6	—	—	—	—
9. xi	1019	119–0	50	8	16	24	48	18	36	—	—
13. xi	1021	120–0	40	32	80	7	16	1	4	—	—
19. xi	1029	100–0	50	9	18	27	54	15	30	—	—
21. xi	1033	113–0	50	16	32	28	56	7	14	—	—
4. xii	1056	100–0	50	1	2	41	82	13	26	—	—
11. xii	1063	334–114	32	5	15·6	17	53·1	5	15·6	5	15·6
31. xii	1085	146–0	50	20	40	13	26	3	6	14	28
1933											
7. ii	1116	110–0	40	7	17·5	25	62·5	—	—	8	20
20. ii	1122	70–0	28	4	14·3	18	64·3	3	10·7	3	10·7
21. ii	1125	97–0	50	26	52	16	32	3	6	8	16
23. ii	1127	100–0	20	4	20	15	75	—	—	1	5
9. iii	1148	117–0	15	6	(46)	9	(54)	—	—	—	—
		330–130	16	16	(100)	—	—	—	—	—	—
10. iii	1150	91–0	7	7	(100)	—	—	—	—	—	—

Four samples were examined from the line taken across the western Drake Passage in October. The three samples from Sts. 988, 990 and 992 show a high percentage of unripe or maturing females or of both. At the other station, 984, nearly all the females were unripe. This was the most northerly station on the line and was in sub-Antarctic water with an average temperature higher than 5·0° C.

Five samples were examined from stations taken in the month of November. At the most southerly (St. 1000), at which the average temperature for the surface 100 m. was lower than − 1·5° C., and at the most northerly (St. 1021), at which the temperature was again higher than 5·0° C., nearly all the females were unripe. At the two stations in the area of maximum abundance of the species (Sts. 1019 and 1029) 36 and 30 per cent respectively of ripe females were found and the remainder of the two samples consisted of maturing females, many of which, at St. 1029 at any rate, were almost ripe. At St. 1033 again, taken in Weddell Sea water colder than 0° C., the majority of the adult females were still maturing and 32 per cent were unripe.

Three samples from stations taken in December were examined, two from Bellingshausen Sea water (1056 and 1063) and one from Weddell Sea water (1085). At St. 1056, very early in the month, the sample consisted mainly of maturing females, with 26 per cent which were ripe or nearly ripe. At St. 1063 in the middle of the month and St. 1085 at the end of the month spent females made their appearance. The remainder of the sample from St 1063 consisted of maturing females and ripe and unripe specimens in equal proportions. At St. 1085 there was a large proportion of unripe and maturing specimens, but while the proportion of "spent" females was high that of "ripe" females was very small. The population at this station, which was taken in Weddell Sea water, almost certainly contains a high proportion of females from the Weddell Sea area itself. Thus the population is probably a mixture of matured and "spent" stock belonging to the Bellingshausen Sea water and a still immature stock from the Weddell Sea water.

Thus far the table indicates that the eggs were shed at the end of November and the beginning of December in the waters of the Drake Passage and western Scotia Sea in which the average temperature for the surface 100 m. lies between 0 and perhaps 3·0 or 4·0° C. At stations where the surface temperature is lower than 0 or higher than 3·0 or 4·0° C. the ripening of the eggs appears to suffer delay (Sts. 984, 1000, 1021, 1033 and 1085).

There are, unfortunately, no observations for January, but four samples were examined from stations taken in February. At St. 1116, in the Drake Passage, a high proportion of the sample consisted of spent females, but the proportion of maturing females was also high. At Sts. 1125 and 1127 at the end of the month, between the Falklands and South Georgia, the samples consisted mostly of unripe females (1125) or maturing females (1127). The maturing females at these stations in February must belong to a new generation resulting from eggs shed earlier in the summer, since ripe females appeared in this region in November. Similarly at Sts. 1148 and 1150 in March, taken in the East Wind Drift current flowing into the Weddell Sea, the unripe and maturing females, of which the samples consisted, must also be an advancing new generation of adults.

Appearance of adult males. The small proportion of adult males in the catches of oceanic copepods is well known. Ottestad (1932) and Wolfenden (1911) drew particular attention to the absence of the mature male from the collections of *Calanus acutus* made by the 'Vikingen', 'Discovery', 'Gauss' and 'Belgica'. Several authors, however, have found that at certain short periods during the year the proportion of male to female adults suddenly increases very greatly. The period of increase is followed by a much longer period during which males are almost absent or present only in small numbers. This sudden appearance of males was usually found to precede the appearance of nauplii and young stages, and to follow or coincide with the appearance of females with ripe eggs in the oviducts. Thus Sømme (1934, p. 77) found males of *C. hyperboreus* "only exceptionally outside the period 15. xii to 15. ii, but within that period even a short time with a surplus over the number of females.... Towards the end of the time when females with eggs in the oviducts are found, that is to say just before spawning, they (male adults) are already found to be present in very small numbers." Sømme expressed the opinion that the adult male has a very short life period, perhaps less than two months. Farran (1927) also found males of *C. finmarchicus* in excess of females only during the month of January, but a fairly high proportion also during May. He was unable to relate their appearance to that of ripe females. Ruud (1929) found a high proportion of adult males of *C. finmarchicus* present in May 1926 and 1927 at a number of stations taken off the coast of Norway between February and July of those years. Their appearance preceded the May-June spawning. Paulsen (1909) found large numbers of adult male *C. finmarchicus* appearing in June off Iceland, in sharp contrast to the small numbers taken in the preceding and following months. He correlated their appearance with the spring period of reproduction.

Table V *a–c* and Fig. 18 show the percentage of males among the adults of *Rhincalanus gigas* taken in the Falkland Sector during the seasons 1931–2 and 1932–3. Those stations at which the number of adults was too small to give true percentage figures have been omitted from the figure and are placed in brackets in the table. A few stations taken in April in the south Indian Ocean have also been included in the table and in the figure. In the season 1931–2 the proportion of males rose suddenly in the middle of December from a maximum of less than 10 per cent of the adults in the catch, and an average of less than 5 per cent, to a maximum of 32·8 per cent. The figure suggests perhaps that the proportion of males decreased more slowly than it increased and continued high throughout December. In the season 1932–3 the proportion of males to females increased more slowly from early in November and reached its maximum in the first week in December, continuing high throughout that month. The appearance of adult males thus coincides with the time of shedding of the eggs—so far as that can be fixed from the scanty data available. It will be seen later (p. 326) that nauplii made their appearance in the catches in the season 1931–2 in the middle of December, when adult males reached a maximum, so that fertilization, shedding and hatching of the eggs must take place within a very short time. It is not possible to know when the nauplii taken in the middle of December were spawned, but it seems unlikely that they represent the

earliest nauplii to be hatched, since nauplii never made their appearance at any subsequent time during the season, and, as will be seen (pp. 326, 328), young copepodites were taken at the end of the first week in January. It is thus at least evident that a very short time, perhaps not more than a week, elapses between the shedding and hatching of the eggs.

It will be seen from Table V *a–c* that the proportion of males is almost always higher in the deep nets (250–100 m.) than in the shallow hauls (100–0 m.). At many stations where males occurred in the lower haul none was taken at all in the upper net, and, during the maximum period for adult males, the percentage of them in the upper nets underwent no increase. It is evident that adult males are more restricted in vertical

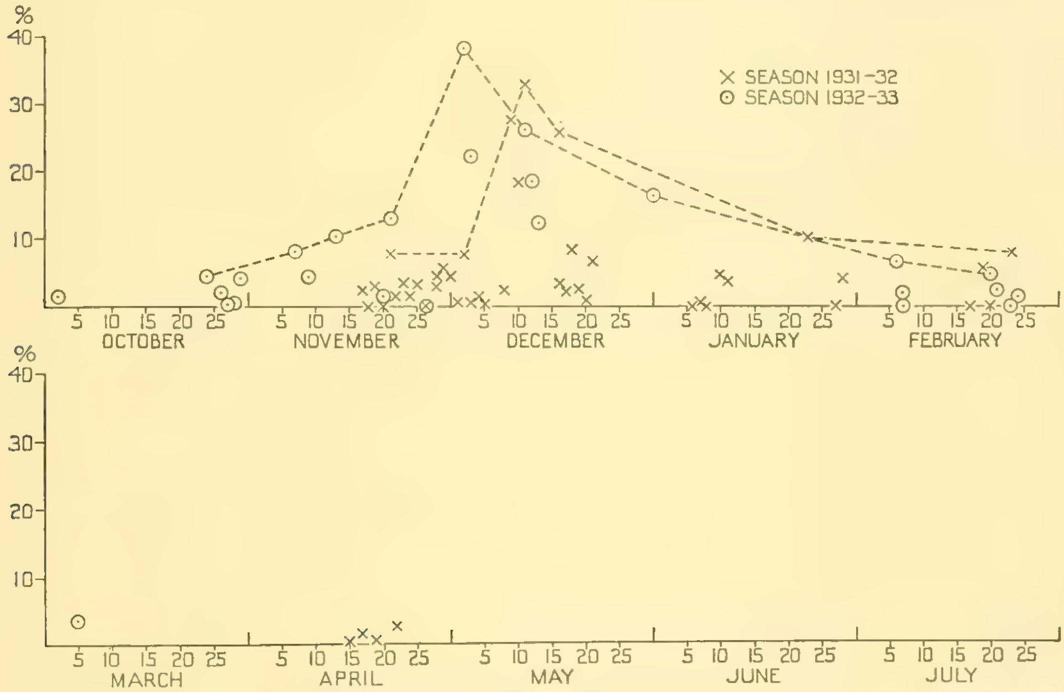

Fig. 18. *Rhincalanus gigas*. Adults. Percentage of males in total adults (upper and lower hauls combined). Falkland Sector, 1931–2 and 1932–3 and Indian Ocean Sector, April 1932.

distribution than females, which occurred in equal abundance in both nets. Paulsen (1909) found the adult males of *Calanus finmarchicus* at greater depths than the females, and Störmer (1929, p. 25) wrote: "The adult (*C. finm.*) female occurs for the most part at 100–50 m. or scattered throughout all depths. The adult males are found at 300–50 m." Male copepodites of *Rhincalanus gigas* in stage v are nevertheless found equally abundantly in both nets, so that restriction to layers below the 100-m. level is peculiar to the adult. If this is the case then only those females which are below the 100-m. level during the summer time will be fertilized. Nauplii and young forms, as Störmer found for *Calanus finmarchicus*, are taken at the surface, so that either the fertilized females must rise to the surface to shed their eggs or the eggs must rise to the surface after they are shed. The curves showing the composition of the *Rhincalanus* stock in stages, to be studied in the following sections of this paper, perhaps hint that the adult females

descend below the 100-m. level before being fertilized, since at the majority of the stations taken in the Drake Passage and Scotia Sea (Figs. 19, 20) during the spring (1931–2), the proportion of adults is a good deal higher in the lower than in the upper nets especially after the end of November (p. 326). There is no marked difference at any time in the proportion of stage v female copepodites in the upper and lower nets.

As a comparison with the figures given in the above section for adult males in the Falkland Sector during the summer seasons 1931–2 and 1932–3, the following figures of Schmaus and Lehnhofer (1927) may be quoted giving the numbers of adult males and females collected by the 'Valdivia' between November 29 and December 10, 1898, from the region south of South Africa. The percentage of males which these figures represent has been added.

Date 1898	No. of females	No. of males	Males %
29. xi	348	28	7·4
2. xii	634	82	11·4
5. xii	153	20	11·5
7. xii	125	12	8·75

These hauls were taken with a vertical net 1·5 m. in diameter, fished from depths between 1000 and 2000 m. to the surface. The percentages are about the same as those found for the same time of year in the Falkland Sector in 1932, but slightly higher than those for December 1931.

THE APPROACH OF THE STOCK TO MATURITY. The discussion of the composition of the *Rhincalanus* stock in stages, which forms the following section of this paper, shows that in the season 1931–2 the population reached maturity in December and that adults began to predominate in the catches from about the end of the first week of that month. In 1932–3 the population would seem to have become mature earlier. Adults predominated at all the stations from the middle of November onwards. Most of the stations at the end of November and the beginning of December, however, were taken in Weddell Sea water. In the first season, 1931–2, there were no observations from December 21 to January 6, but on January 7 (St. 796) and on January 10 (Sts. 802 and 803) adults were very few and a new generation had made its appearance and predominated in the catches. Nauplii were taken on December 18 (St. 778). In the second season, 1932–3, observations were lacking for January and the new generation was taken in February (Sts. 1116, 1117, 1125, 1127).

COMPOSITION OF THE STOCK OF *RHINCALANUS GIGAS*

The only examination of the population of *R. gigas* in Antarctic waters from the viewpoint of the composition of the stock in copepodite stages which has yet been made is that of Ottestad (1932).[1] This author examined the material from fourteen stations taken

[1] A further paper by Ottestad has appeared while this report was in the press, see pp. 293 and 356.

in the season 1929–30 by the 'Vikingen' and one taken by the 'Norvegia' in 1928. Some of these stations were taken in water flowing out of the Weddell Sea between the South Sandwich Islands and Bouvet Island, and some in Weddell Sea water south of the South Sandwich Islands and east of the South Orkneys.

The conclusions at which Ottestad arrived from the data at his disposal will be seen to be largely confirmed in what follows. He found that two age groups were distinguishable in the population taken at the earlier 'Vikingen' stations at the end of November and early December. One of these consisted of stages ii, iii and iv, and the other, the older one, of stages iv, v and vi. In the latter half of December the older of these two groups had disappeared. At the Norvegia station, taken in mid-January 1928, the older group had disappeared and the younger group had advanced to stages iv, v and vi. Ottestad concluded (p. 51), since he never found nauplii or stage i at any of the stations taken by the 'Vikingen', "that the stock existing in the Weddell Sea is due to an invasion from another spawning area". He suggested that *Rhincalanus* spends the winter in deep water, rising to the surface before spawning in the spring, and is carried into the Weddell Sea by the "Antarctic Intermediate water" (warm deep water—Deacon, 1933). Of these two last assumptions we have already seen that the former is very strongly supported by the data collected by the 'Discovery II'. The latter assumption we also believe to be correct, though *Rhincalanus* is probably carried into the Weddell Sea to a greater extent by warm deep water originating in the South Indian Ocean (East Wind Drift current) than by water originating in the South Atlantic.

Finally, Ottestad writes (p. 51): "No renewal of the stock takes place in the Weddell Sea as the mature stock disappears without previously spawning...neither is it possible to prove that spawning of this species takes place in the Weddell Sea."

In the present work the copepodite stages were identified according to the description of Schmaus and Lehnhofer (1927). There are, as usual, five copepodite stages between the nauplius and the adult, which is counted as stage vi. Stages iii, iv and v were of frequent occurrence in the hauls, but stages i and ii occurred less frequently and only, presumably, when present in the water in such abundance that they could not all escape through the meshes of the stramin net. Nauplii occurred even less frequently and, again, only presumably when present in immense numbers in the water. It can hardly be expected, therefore, that the numbers of the younger copepodite stages taken in these hauls will be very accurate or give more than an approximate picture of the condition of the population at the stations where they occur.

Drake Passage and South Atlantic Ocean, November 1931 (Fig. 19, Table VI *a*)

Fig. 19 shows the percentage of the various copepodite stages in the catches in the upper and lower nets at stations in the Drake Passage and western Scotia Sea from the middle to the end of November 1931. At the end of November the dominant stages are iv and v at nearly all stations in the Drake Passage. However, it will be noticed that at stations north of the Antarctic convergence (Sts. 725–7, 750 and 751, at the beginning

of December), stage iv is almost absent, stage v is dominant and adults are present in large numbers. In some of the hauls from these stations north of the convergence adults (stage vi) are even dominant. At stations south of the convergence (Sts. 731, 733, 739, 741 and 745), stage iv is usually present in fairly large numbers, especially in the lower hauls, but stages younger than this are absent. At Sts. 735 and 737, the most southerly of the stations in the Drake Passage, fair numbers of stage iii were taken (at St. 735 more than 20 per cent in the lower net). Thus the stock north of the convergence is definitely older than the stock south of it, and the stock in the warmer Antarctic water is apparently older than that in the coldest Antarctic water. Now the stock found at these stations at the western end of the Drake Passage in November 1931 was in the course of or had just completed its spring ascent to the surface. It had just passed the winter at a depth below 250 m. Further, several considerations lead one to believe that the young stages (stage iii) found at the edge of the ice do not result from a recent spawning. In the first place they are not present in sufficient quantities to indicate a recent spawning. At St. 735 only 22·0 per cent stage iv and 11·7 per cent stage iii were found in the two hauls together, and at St. 737 only 26·0 and 9·7 per cent of stages iv and iii respectively. Stage ii was present at each station in very small numbers, and no stage i or nauplii were found. In the second place, we have seen from figures for the following season that the adult females at this time of year are not yet ripe and no males had appeared. It seems evident, then, that in the coldest Antarctic water, with an average temperature less than $-1{\cdot}5^\circ$ C., the stock in the spring, which had just passed the winter below 250 m., contained a proportion of individuals which had not developed beyond stage iii. The stock in the warmer Antarctic water (average temperature below about $3{\cdot}0^\circ$ C.) appears to have developed as far as stages iv and v by the spring and that in water north of the convergence as far as stages v and vi. The population in all these three classes of water probably results from a mid-winter spawning, as we shall see later (p. 338), and it must be assumed either that the stock in Antarctic water with an average temperature less than $-1{\cdot}5^\circ$ C. has been spawned later in the winter than that in warmer Antarctic water (average temperature below about $3{\cdot}0^\circ$ C.), or else that it was spawned at the same time as the stock farther north but that its rate of development has been retarded. Similarly the stock in the warmer Antarctic water must either have been spawned later than the stock north of the convergence or else have developed more slowly during the winter months.

In the main the stock curves of the population in the western Drake Passage in November 1931 show that the species rises to the surface from its winter level principally in stages iv and v, so that one may say that *Rhincalanus gigas*, like other species of oceanic Copepoda (Sømme, 1934, *Calanus finmarchicus* and *C. hyperboreus*; Nicholls, 1933, *C. finmarchicus*; Campbell, 1934, *C. tonsus* and *Euchaeta japonica*; and others) spends the winter months in these two stages.

At the stations in the eastern Drake Passage and in the South Atlantic near the Falklands at the end of November stages iv and v were predominant and the proportion of adults was high in the lower nets.

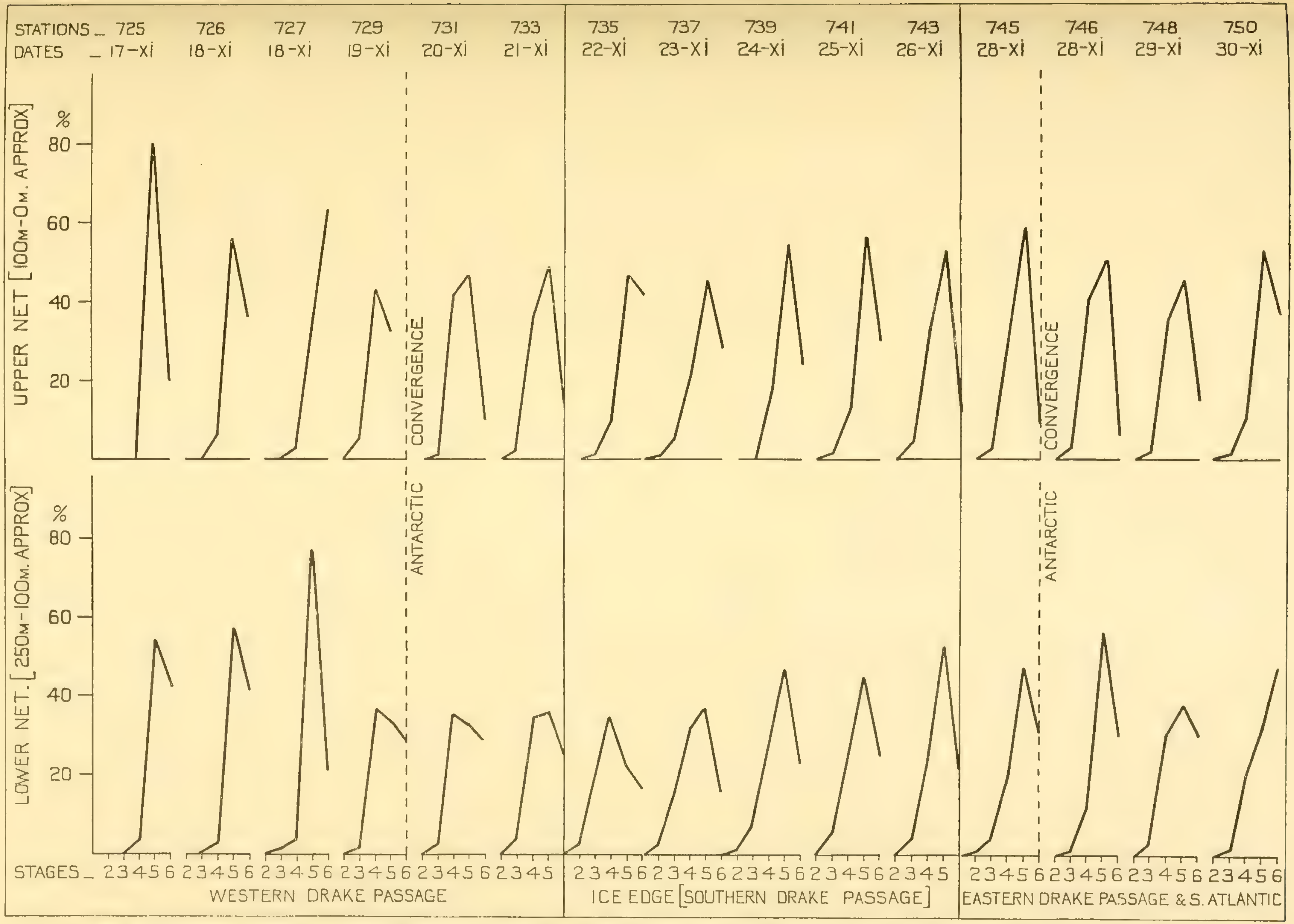

Fig. 19. Percentage of copepodite stages of *Rhincalanus gigas* in 1-m. nets. Drake Passage and South Atlantic Ocean, November 1931. (See Table VI *a*.)

Scotia Sea and South Georgia, December 1931 (Fig. 20, Table VI *b*)

On the line of Sts. 751–759 (Western Scotia Sea), at the beginning of December, conditions were much the same as on the line of Sts. 743–750 at the end of November (Eastern Drake Passage). Stage v still predominated and the proportion of adults was high, except at St. 753.

Early in the season, during the month of November, many of the stations show a high proportion of adults in the upper nets (Sts. 727, 735, 737, 741), and at some others, notably Sts. 726 and 739, the proportion of adults was approximately equal in both the upper and lower nets. In those, however, which were taken after the end of November and in early December in the Drake Passage and Western Scotia Sea (Sts. 743–761), the proportion of adults is higher in the lower hauls than in the upper. This, it has been suggested (pp. 321, 322), may represent a descent of the adult females to a fertilization level coincident with the appearance of a high percentage of adult males in the layers below 100 m.

At the end of the first week in December (St. 763) stage vi (adults) began to predominate in the catches. The appearance of the stock curves for the lower hauls at Sts. 763–768 and 775 is perhaps partly due to the appearance of large numbers of adult males in the lower hauls (Table V *a*). In the upper hauls at these stations, however, adult females were overwhelmingly predominant. Sts. 763–768 were taken in water flowing out of the Weddell Sea, so that it is possible that the population at these stations is a mixed one, consisting partly of the stock from the Drake Passage and partly of that from the Weddell Sea. At Sts. 774, 775 and 776, which were taken in the Bellingshausen Sea current, unmixed with water from the Weddell Sea, the stock is approaching maturity, but contains more stage v than that at the stations in Weddell Sea water south of South Georgia. At St. 776, immediately north of the convergence in this area, there is a surprisingly high proportion of stage iv in the surface haul.

South Atlantic Ocean, East of South Georgia, mid-December 1931 *to mid-January* 1932 (Fig. 21, Table VI *c*)

The stations east of South Georgia, taken in the middle of December and the middle of January, appear to show several different stocks. Firstly there is a stock consisting almost entirely of young forms up to stage iii. These are found at South Atlantic stations in water of Bellingshausen Sea origin (Sts. 796, 802 and 803). In addition to these three stations there is St. 778 (18. xii. 31) at which we find two age groups in the surface haul —an old one consisting of stages v and vi and a young one consisting of nauplii, stages i, ii and iii. The surface net at this station was choked with diatoms so that it is not impossible that it took an unduly high proportion of very young forms. On the other hand, at St. 780, taken the next day in Weddell Sea water, the surface net was similarly choked with diatoms and no young forms were taken at all. Abundant diatoms were also taken in the 1-m. nets at several other stations at this time (Sts. 806, 807, 808 and to a lesser extent 809), but in these again no very young forms were taken. The presence of nauplii and very young stages at St. 778 may therefore legitimately be taken to indicate that

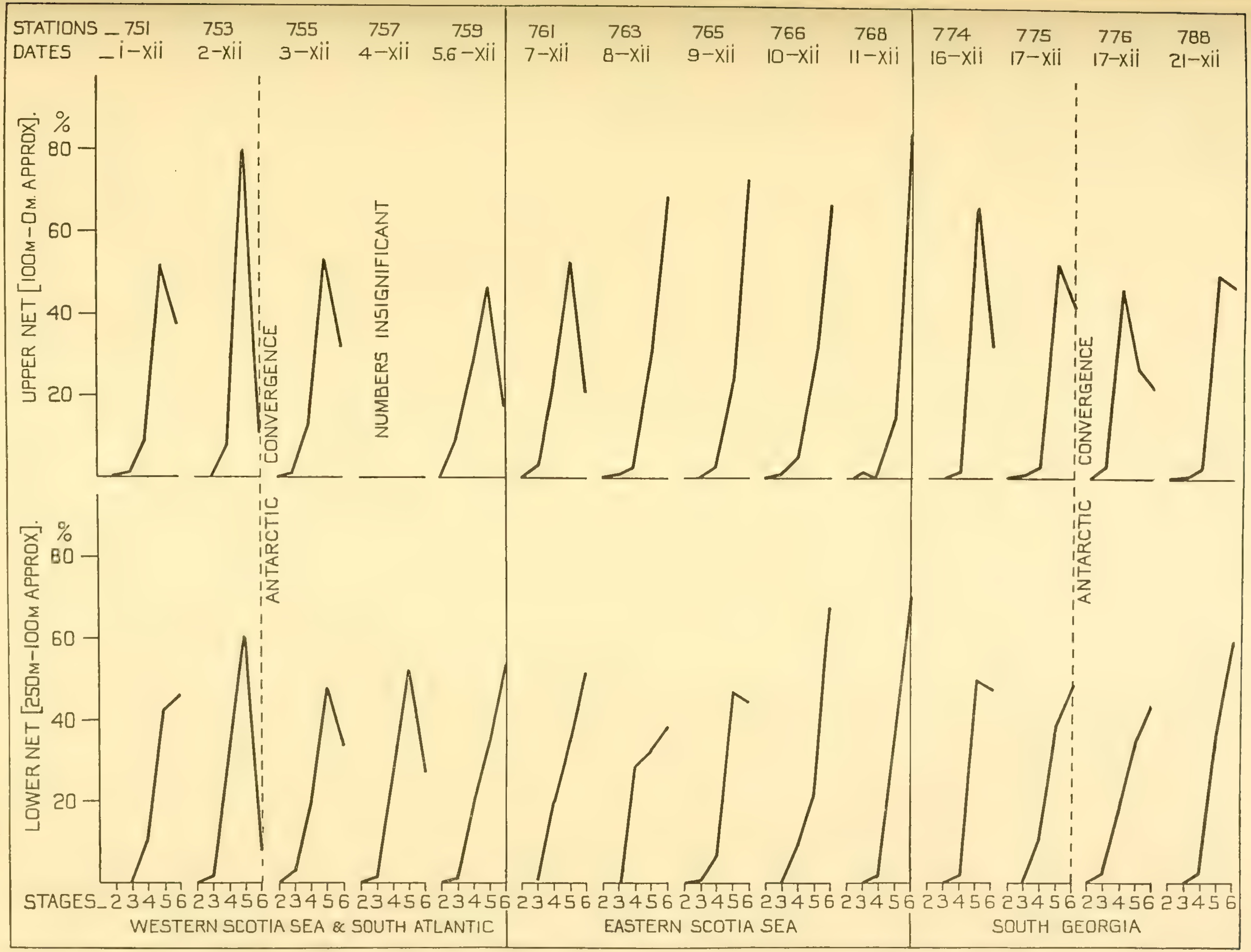

Fig. 20. Percentage of copepodite stages of *Rhincalanus gigas* in 1-m. nets. Scotia Sea and South Georgia, December 1931. (See Table VI *b*.)

spawning had recently taken place and was not due solely to the choking of the meshes of the net. The population at Sts. 796, 802 and 803, then, very probably belonged to the

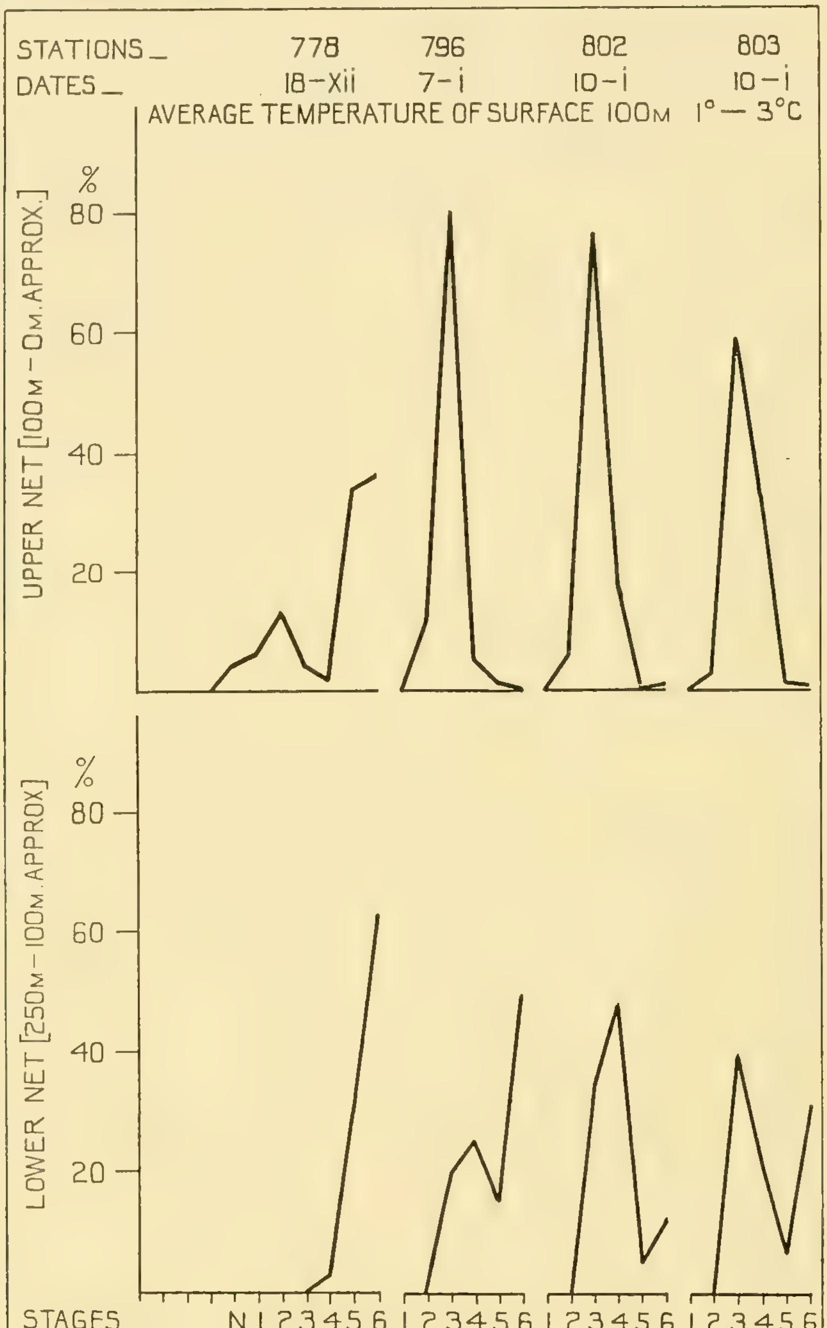

Fig. 21. Percentage of copepodite stages of *Rhincalanus gigas* in 1-m. nets. South Atlantic Ocean east of South Georgia, December 1931 to January 1932. (See Table VI *c*.)

same stock as the young forms at St. 778, which had grown into stage iii in the intervening three weeks (18. xii. 31 to 7. i. 32). It seems to be quite a legitimate supposition that nauplii and stages i and ii should have grown into stage iii in this short time. In

the northern hemisphere the rapidity of growth of the summer generation of copepods has frequently been commented upon. Ruud (1929) found that about seven weeks elapsed between the maximum for nauplii and the maximum for adults of *Calanus finmarchicus* off the coast of Norway, and gave about three months as the time required for the complete life cycle, including the embryonic development. Lebour (1916), from Crawshay's cultures at Plymouth, gave only two months from the egg to stage v. The population at Sts. 796, 802 and 803 had drifted probably from the region of South Georgia in the West Wind Drift (Bellingshausen Sea current) since spawning. At all these stations (778, 796, 802 and 803) it will be noticed that the old parent generation was found in the lower nets. The greatest number of the old generation was taken at St. 778; fewer, with some of the new generation stage iv, at St. 796; more stage iv and fewer of the old generation at St. 803, and very few of the old generation at St. 802. Thus the old generation appeared to die out as it became carried away from South Georgia. It may also be noted that the stock at St. 803 in the surface haul was slightly older than the stock at either Sts. 796 or 802. It contained more stage iv and fewer stage ii and must be supposed to have been spawned slightly earlier than the stock at Sts. 796 and 802. St. 803 lay between the 2·0 and 3·0° isotherms, while Sts. 796 and 802 lay between the 1·0 and 2·0° isotherms. It looks, therefore, as though spawning had taken place somewhat earlier in warmer water (2·0–3·0°) than in the colder water (1·0–2·0°).

We have now a picture of the spawning of *Rhincalanus gigas* taking place in this season in the Bellingshausen Sea current in South Atlantic water east of South Georgia probably in the first fortnight in December. No spawning seems to have occurred west of the island at this time, since at St. 788, taken west of South Georgia in the third week in December (Figs. 1*a*, 20), a maturing stock was still found with no young forms at all. The spawning apparently took place earlier in water warmer than 2·0° C. than in water with a temperature lower than this.

It appears that the spawning took place in Antarctic water, since at St. 776 (Figs. 1*a*, 20) in the sub-Antarctic zone the population at this time consisted of stages iv, v and vi with no trace of a new generation. It is hardly possible that the high proportion of stage iv in the surface net at this station can represent the product of a recent spawning since almost no stages younger than this were found and the remainder of the stock consisted of stages v and vi. At St. 775, eighty miles farther south on the Antarctic side of the convergence, the population also consisted of the old generation in stages v and vi. It is perhaps worthy of note that evidence of spawning was found at the stations in the area where Antarctic water from the Bellingshausen Sea comes into contact with water from the Weddell Sea, but that no trace of spawning was found at this time in the same water away from the influence of the Weddell Sea (Sts. 774, 775 and 788). As will be seen later (p. 334) there was found in February between the Falklands and South Georgia a very scanty population on the sub-Antarctic side of the convergence in stage iii, which was judged to be the result of a very greatly diminished spawning which took place in sub-Antarctic water much later than the main spawning in Antarctic water.

There is no doubt that spawning takes place in any given locality at different times in different seasons. In 1931–2 it took place east of South Georgia in the first fortnight in December. In 1929–30, however, Ottestad found a young generation in stages ii, iii and iv already developed at the end of November and the beginning of December. The Vikingen stations were taken considerably farther east at this time than the most easterly of the Discovery II stations in early January 1932. In the season 1929–30, therefore, spawning must have taken place east of South Georgia somewhere about the beginning of November. It is probable that the time of spawning depends on some variable factor, and one may suggest, as the most likely one, the break-up of the pack-ice and the southward movement of the isotherms in this area. The season 1929–30 was an exceptionally mild one; the pack-ice was far south and there was no sign of it around the South Sandwich Islands. In the season 1931–2 the pack-ice was north of the South Orkneys at the end of the first week in December and around the South Sandwich Islands probably in early January. It may be that the difference in the time of break-up of the pack in the two seasons accounts for the difference in the spawning time of *Rhincalanus*.

Weddell Sea, mid-December 1931 *to mid-January* 1932
(Fig. 22, Table VI *c*)

We have now to examine the *Rhincalanus* populations at the remaining stations in the South Atlantic area. They all lie in the Weddell Sea current, and it will perhaps be best to consider them in relation to the Weddell Sea as a whole.

At stations in the "oldest" Weddell Sea water (average temperature for 0–100 m. between 0 and 1·0° C.)—Sts. 779, 795, 798, 806 and 808—the catches (except at St. 779) consist of stage v, with varying proportions of stage vi. No young forms were found at any of the stations in the Weddell Sea, except at St. 804, where a fair proportion of stage iv were taken in the upper net together with a very few stage iii. From this fact one may conclude that before the end of January, at any rate, no spawning took place in the Weddell Sea. At each of the stations in the "oldest" Weddell Sea water (0–1·0° C.) the larger proportion of the catch was in the lower nets and hence it may be supposed, as already mentioned, that the population originated mainly from the warm deep water of the South Atlantic or Scotia Sea, which here mixes with colder Weddell Sea water at the surface above about 200–250 m. At these stations (Fig. 22) the stock consisted predominantly of stage v. At the most westerly station (779) in the "oldest" Weddell Sea water the stock consisted predominantly of adults. At Sts. 763, 765 and 768, taken in the Scotia Sea in water of Weddell Sea origin (Table VI *b*, Fig. 20), it must be assumed that the population in both nets is of mixed origin, since a high degree of mixing takes place in this particular area. However, the main body of the catch at these stations occurred in the upper nets, so that most of the population sampled by them is perhaps derived from Antarctic surface water which has spent some time in the Scotia Sea, since the water derived most recently from the Weddell Sea will probably be concentrated in the lower stratum of the surface layer. Adults

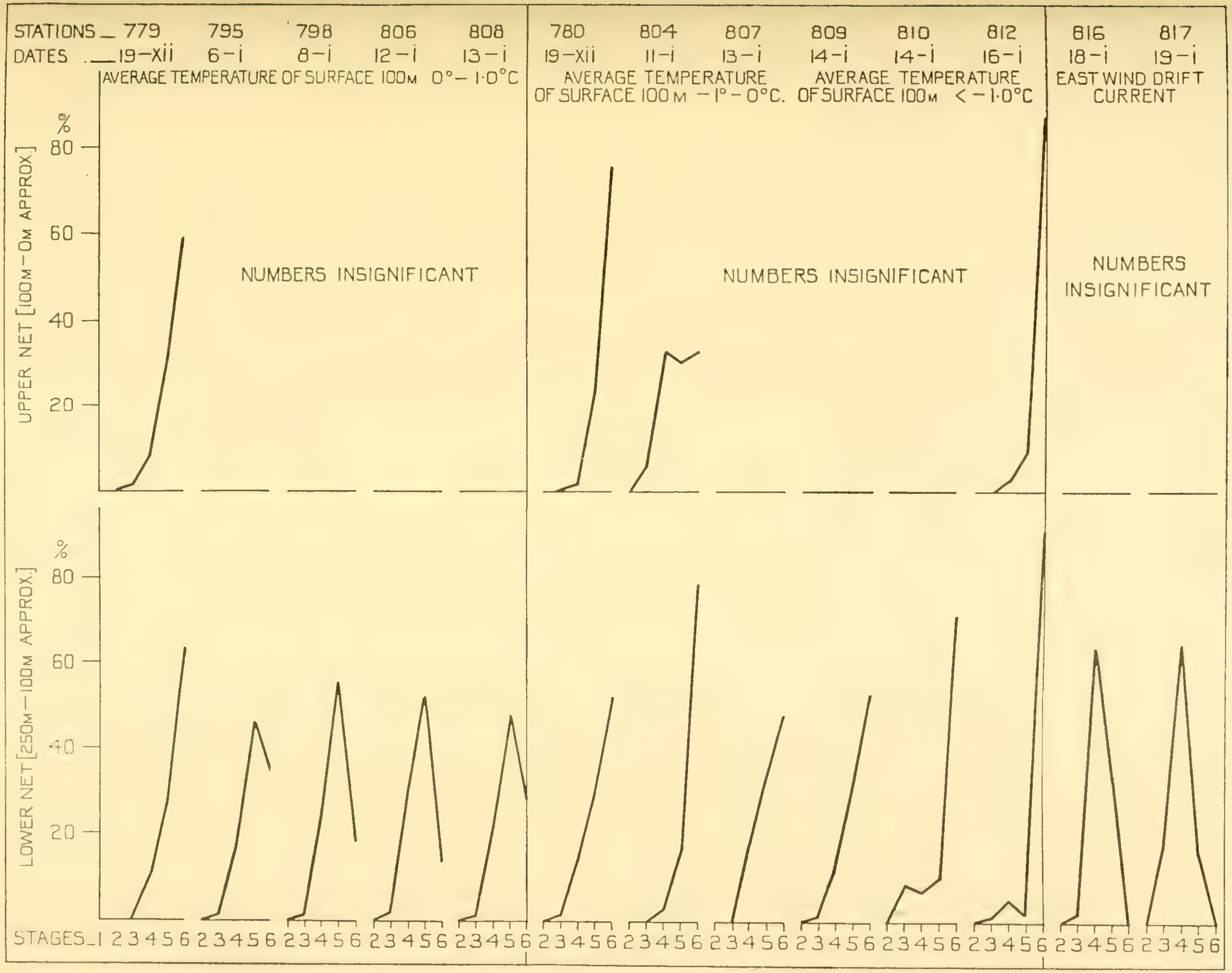

Fig. 22. Percentage of copepodite stages of *Rhincalanus gigas* in 1-m. nets. Weddell Sea, December 1931 to mid-January 1932. (See Table VI *c*.)

predominated in the upper nets, and in the lower nets adults and stage v appeared to predominate in about equal proportions. The predominance of adults in the lower nets at these stations, however, is largely due to the increased proportion of adult males.

Thus the *Rhincalanus* population of the Bellingshausen Sea current, when it became carried into the colder Weddell Sea water where the temperature was below 0° C., appears either to have been prevented from reaching maturity by the middle of January, as at Sts. 795, 798, 806, and 808, or, as at Sts. 763, 765, 768 and 779, to have reached maturity but failed to spawn.

At the stations in Weddell Sea water containing melting or recently melted pack-ice (−1·5–0° C.) the stock consisted mostly of adults with varying proportions of stage v. At only two stations did stage v predominate (Sts. 809 and 815), but at these the size of the catches was possibly too small to give accurate percentages. At St. 804 a fair proportion of stage iv was taken, possibly carried southwards in Atlantic deep water. At all these stations in Weddell Sea water with a temperature below 0° C. it seems probable, from the complete absence of young stages, that we are dealing with a population which had failed to spawn, and at Sts. 810, 812, 822 and 823—the most centrally situated in the Weddell Sea—the scarcity of stages younger than stage vi (adult) is very striking. The population in this water (less than 0° C.) is being carried northwards out of the Weddell Sea in the north-easterly current, and it may be suggested that this is an over-wintered stock, resulting from the previous winter's spawning, which was carried into the Weddell Sea by warm deep water of the East Wind Drift.

Finally we come to the stations in the East Wind Drift current flowing westwards into the Weddell Sea south of 66° S (Sts. 815, 816 and 817). We find that the stock at these three stations consisted of stages iv (at Sts. 816 and 817) and stage v (at St. 815). Further, the catches were entirely in the lower nets. This is a population which, from its age, must have been spawned earlier on during the current summer somewhere to the east off the coast of Coats Land. At any rate, since there are no signs of a parent generation, it is reasonable to suppose that this stock had been spawned a considerable distance away, perhaps outside the Weddell Sea; that it was the same stock, therefore, as that found at Sts. 796, 802 and 803 and that it had been carried into the Weddell Sea by the westward-flowing warm deep water of the East Wind Drift current originating in the South Indian Ocean. It thus seems probable that the population at Sts. 810, 812, 822, 823 and perhaps 780 consisted of a similar stock carried into the Weddell Sea during the preceding winter or even during the previous season, and the adults of which this stock consisted must have been over six months or perhaps over a year old.

Weddell Sea and Eastern Scotia Sea, end of January 1932 (Fig. 23, Table VI *c*)

At St. 824 (27. i. 23; Fig. 1 *b*) we again encounter a stock which was probably of mixed origin, as was suggested for the population in this region during December (Sts. 766–768, p. 330). It probably originated partly from the Bellingshausen Sea water of the Scotia Sea and partly from the Weddell Sea. It consisted almost entirely of stages v and vi—stage v in the upper and stages v and vi in the lower nets. It is probably similar

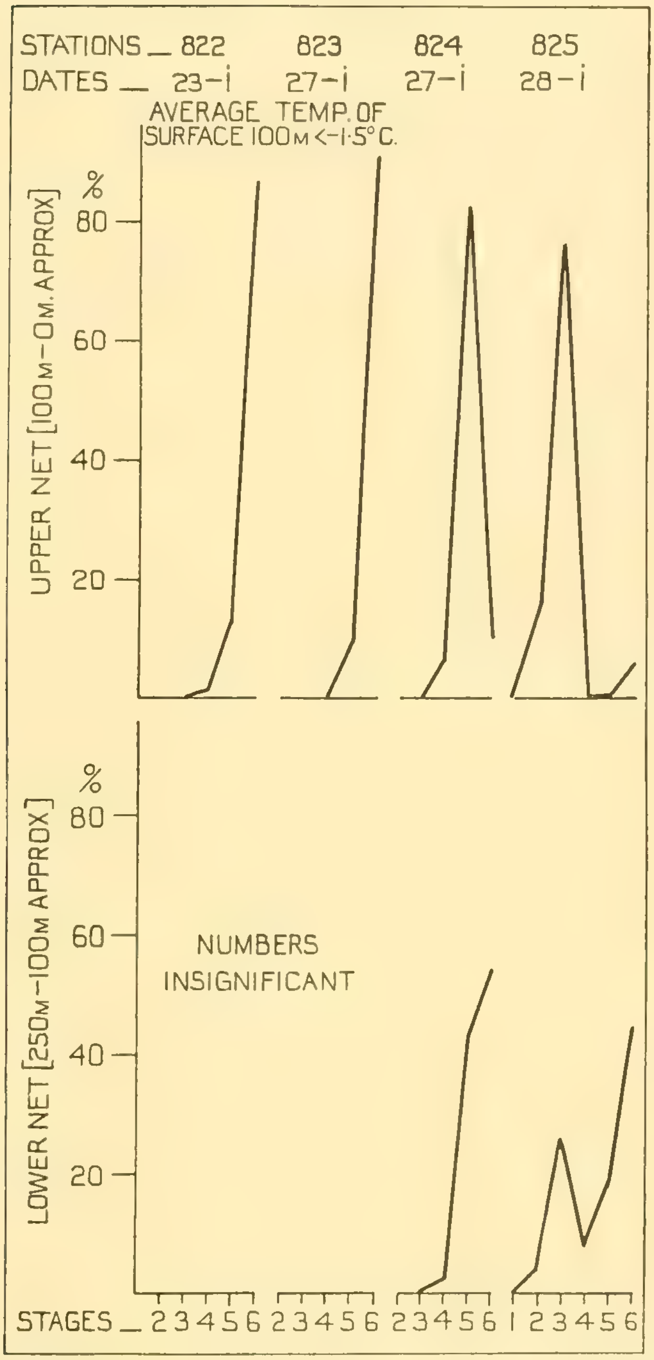

Fig. 23. Percentage of copepodite stages of *Rhincalanus gigas* in 1-m. nets. Weddell Sea and Eastern Scotia Sea, end of January 1932. (See Table VI *c*.)

to the population found in the "oldest" type of Weddell Sea water (0–1·0° C.) at the beginning of the month (Sts. 795, 798, 806 and 808), and represents that the part of the population of the Bellingshausen Sea current in the Drake Passage which had failed to reach maturity by the end of January, through having drifted into Weddell Sea water with a temperature lower than 1·0° C. At St. 825 (Fig. 1 *b*), however, we find the stock consisting almost exclusively of stage iii. This must result from a fairly recent spawning and part of the parent generation remains, particularly in the lower haul. It will be noticed that the stock here in the Scotia Sea at the end of January is of the same age as that found during the first week of the month at Sts. 796, 802 and 803 (Fig. 21). Now the population sampled at St. 825 must result from a spawning which took place to the south-west in the Scotia Sea in water of Bellingshausen Sea origin, where the temperature, according to the isotherm map (Fig. 5), may have been less than 0° C. This spawning, then, must have taken place, if the rate of development is the same in all waters, at least three weeks later than that which took place east of South Georgia at the end of December and which gave rise to the stock at Sts. 796, 802 and 803 (Fig. 21). Alternatively the spawning took place at the same time, but the growth rate in the water of lower temperature has been slowed down.

Falkland Islands to South Georgia, mid-February, 1932 (Fig. 24, Table VI *d*)

On the line from the Falklands to South Georgia in the middle of February we find small catches at Sts. 828 and 829 (Fig. 1 *b*), in sub-Antarctic water, consisting of stage iii and no trace of a parent generation.

The disappearance of *Rhincalanus gigas* from sub-Antarctic water at the end of the summer has already been commented upon (pp. 299, 311, 312). In the light of what we have seen of the course of events during the summer two explanations may perhaps be advanced to account for the difference between the summer and winter conditions on the sub-Antarctic side of the convergence. There is at present, however, no evidence to prove which, if either, of the suggested explanations is correct. It might be supposed that the *Rhincalanus* population begins the descent to its winter level much earlier north of the convergence than south of it. This was found to be true to a certain extent by Mackintosh (1935), who has shown that it was to the north of the convergence in March 1934 that *R. gigas* first began to seek its winter level. But this hardly seems sufficient to account for the great reduction in the catches within the surface 250 m. in sub-Antarctic water so early as February in the seasons 1931–2 and 1932–3. If, however, this theory is correct the population sampled at Sts. 828 and 829 in February 1932 was part of a stock of which the main body lay at a level below 250 m. and was therefore out of range of the nets. An alternative, and possibly more probable, explanation is that spawning is very reduced in sub-Antarctic water during the summer, so that when the over-wintered generation dies out in late January or February there is only a very greatly diminished summer spawned advancing generation to replace it. The absence of a parent generation from the stock at Sts. 828 and 829, in which stages ii and iii predominate might suggest that this population was not spawned in the water in which it was taken. It is

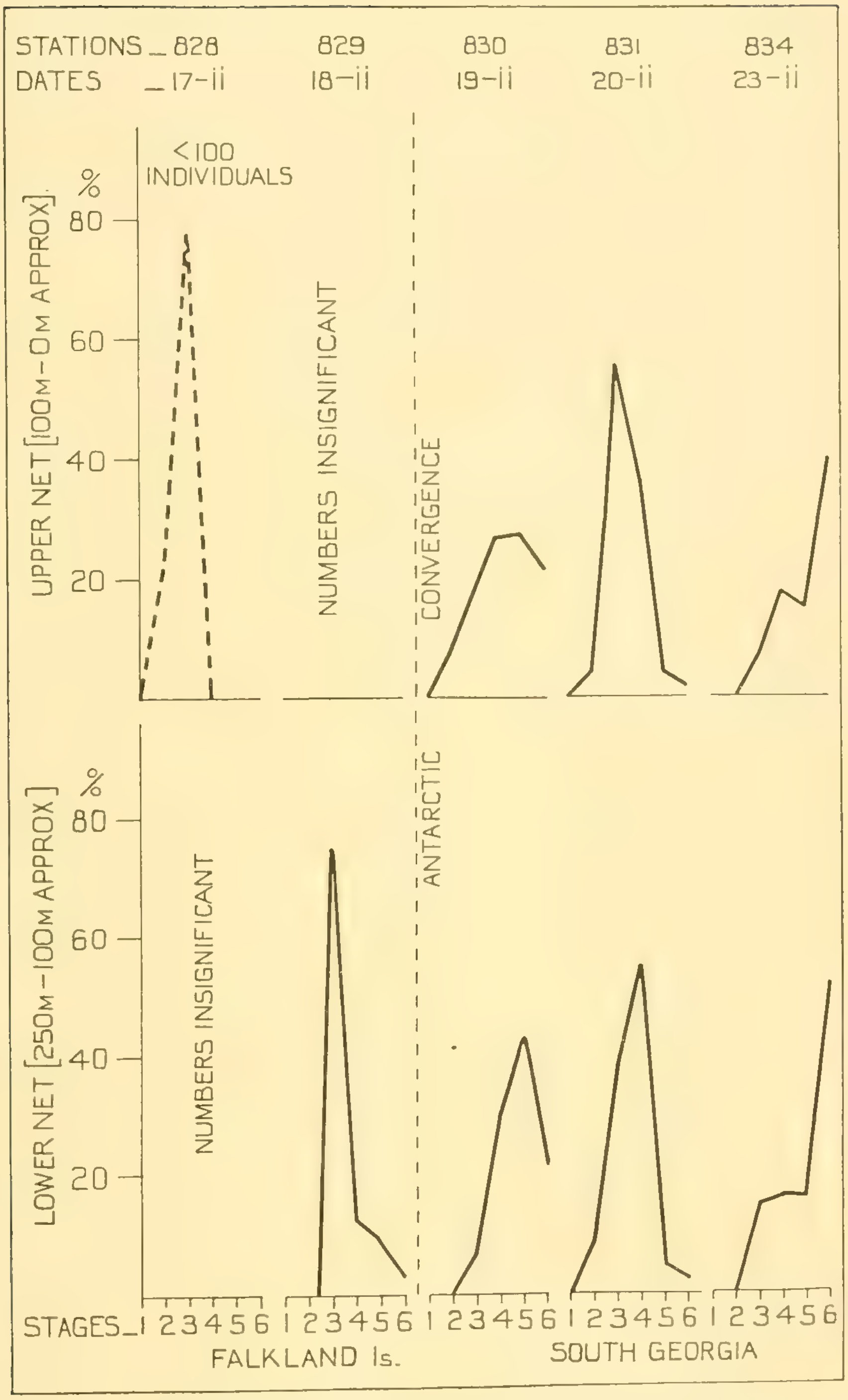

Fig. 24. Percentage of copepodite stages of *Rhincalanus gigas* in 1-m. nets. Falkland Islands to South Georgia, mid-February 1932. (See Table VI *d*.)

evident, in view of its age, that it was spawned considerably later than the population on the Antarctic side of the convergence, but perhaps about the same time as that sampled at St. 825 at the end of January. However, at both these stations (828 and 829) on the sub-Antarctic side of the convergence the catches are too small to allow conclusions to be drawn from them; but if this is the correct explanation of the disappearance of the *Rhincalanus* population from sub-Antarctic water at the end of the summer, it must be supposed that the over-wintered stock is carried northward across the convergence by Antarctic surface water on reaching the upper layers in the early spring. This would account for the large catches of *Rhincalanus* in sub-Antarctic water early in the year but one must suppose that most of the population in this water dies out without spawning during the summer.

At the two stations (830 and 831) on the Antarctic side of the convergence, we find that the catches were enormously greater than on the sub-Antarctic side, though somewhat reduced compared with the same locality in November (Figs. 8, 10). Two distinct stocks are found here also (Fig. 24), one consisting mainly of stages iv, v and vi, at the warmer station (830, 4·15° C.), and a younger stock consisting of stages iii and iv at the colder station (831, 2·74° C.). It may be suggested that the stock at St. 830, just on the Antarctic side of the convergence, was spawned in the eastern Drake Passage in water with an average temperature higher than 1·0° C. but lower than 4·0° C. (see Fig. 5). The stock at St. 831 must also have been spawned in the eastern Drake Passage, but in water with a temperature lower than 1·0° C. (see Fig. 5). Its age indicates that it was spawned later than the stock in the warmer water near the convergence (St. 830), so that again spawning has been delayed in the water of lower temperature. It is seen that the stock in the Bellingshausen Sea current immediately west of South Georgia in the latter half of February consisted mainly of stages iii and iv (Fig. 24; St. 831), so that it was not much farther advanced in age than the population sampled in the same water in the South Atlantic east of South Georgia during the first half of January (Fig. 21; Sts. 796, 802 and 803). Near the convergence, between the Falklands and South Georgia (St. 830), the population is older, mainly in stages iv and v, but still younger than might be expected if it had been spawned at the same time as the stock east of South Georgia earlier in the season. It is evident then that the spawning in the eastern Drake Passage, where the population at Sts. 830 and 831 originated, must have taken place considerably later in the season than the spawning in the South Georgia area. It occurred earlier in the warmer eastern Drake Passage water, however, than in the colder water, as may be seen from the difference in the ages of the populations sampled at the two stations 830 and 831.

SUMMARY, FALKLAND SECTOR, SEASON 1931–2

1. *Rhincalanus gigas* passes the winter generally in copepodite stages iv and v, as has been found for species in the northern hemisphere (p. 324).

2. In waters north of the Antarctic convergence (warmer than 4·0° C.), however, it appears that many individuals may reach stage vi by November. In Antarctic water

colder than $-1 \cdot 5°$ C. many individuals do not develop beyond stage iii before the spring (pp. 324, 326).

3. In the Scotia Sea and around South Georgia the population was found to be mature (in the adult stage) about the end of the first week in December (p. 326).

4. Nauplii and very young stages were taken at one station in South Atlantic water of Bellingshausen Sea origin in the middle of December (St. 778, 18. xii. 31). At the end of the first week in January in this water an advancing summer generation was found in stage iii (p. 326).

5. In the oldest type of Weddell Sea water (0–1·0° C.), the population was mainly in stage v—except at Sts. 763, 765, 768 and 779, where it was mainly in the adult stage (stage vi) (p. 330).

6. In water flowing out of the Weddell Sea having an average temperature for 0–100 m. below 0° C. the population consisted almost entirely of adults and was taken in the upper nets. No young forms were found at all. In water flowing into the Weddell Sea along the coast of Coats Land south of 66° S the population consisted mostly of stage iv and was found in the lower nets (p. 332).

7. A population again in stage iii was found at one station (825) in late January in the Scotia Sea south of South Georgia (p. 334).

8. Between the Falklands and South Georgia in the middle of February two stocks were found—one in stages iv, v and vi in warmer Antarctic water and another in stages iii and iv in colder Antarctic water near South Georgia. A much reduced young population was taken in sub-Antarctic water (p. 336).

9. From the above facts it has been concluded that the spawning of *R. gigas* took place during the season 1931–2, in the Falkland Sector, in December and probably throughout January. It occurred first in Antarctic water from the Bellingshausen Sea in the South Atlantic, where the temperature was between 1·0 and about 4·0° C. Spawning in the Scotia Sea and eastern Drake Passage took place later, also in water from the Bellingshausen Sea. There is evidence that the spawning everywhere took place earlier in warmer than in colder Antarctic water. The part of the *Rhincalanus* stock belonging to the Bellingshausen Sea current which drifted into the "oldest" type of Weddell Sea water (0–1·0° C.) failed to reach maturity by the middle of January. No spawning at all apparently took place in Weddell Sea water with a temperature below 0° C. at least before the end of January. The population found in the southern Weddell Sea, in the middle of January, in water flowing in from the east south of 66° S, was judged to be the same advancing summer generation as was found in the South Atlantic at the beginning of the month. The population of the Weddell Sea is thought to result from an invasion from an outside area and to be carried into the Weddell Sea either in Atlantic warm deep water, or in the deep current originating in the South Indian Ocean which flows into the Weddell Sea south of 66° S along the coast of Coats Land. A late and much reduced spawning appears to have taken place in sub-Antarctic water.

South Indian Ocean and Australian Sector. Winter months, April, May, June 1932 (Fig. 25, Table VI *e*)

Fig. 25 shows the population analysed into stages in the South Indian Ocean in April, at three stations in the Australian Sector in May and one in June.

The population in April in the Indian Ocean Sector is younger than one would expect if spawning had taken place in December, as it apparently did in the Falkland Sector. Stages iii, iv and v are the dominant stages in different proportions. At St. 851 particularly large numbers of stage iii were taken in the surface haul. In the absence of further data we must conclude that spawning took place later in this sector of the Antarctic in the season 1931–2 than it did in the Falkland Sector.

On the line from Enderby Land to Fremantle, where the catches were in the lower nets, the stock consisted mainly of stage v, with a high proportion of stage iv (35–40 per cent). At the most northerly station (862) there was a high proportion of stage iii. In the absence of more complete data it is not possible to do more than note that the population in the warmer waters of the Antarctic Zone at this time of year seems to have been younger than the population in the colder water. The explanation of this might perhaps lie in the different vertical distribution of the various copepodite stages in different places. It is seen that adults were quite absent from the line from Enderby Land to Fremantle, although present in large proportions, especially in the lower nets, on that from Cape Town to Enderby Land. They have presumably sunk below the 250-m. level on the line to Fremantle. Thus also it may be that more stage v copepodites have sunk below the 250-m. level at St. 862 than at St. 860 and more again at St. 860 than at the two more southerly stations.

At St. 887, at the pack-ice edge south of Australia at the end of May, we find that a spawning had evidently recently taken place. Great numbers of stages i and ii, with nauplii, were taken in the surface net. This is the only station in the Australian Sector at which any *Rhincalanus* were taken in the surface net, and the catch was a comparatively large one (533), while the number in the lower haul was insignificant (54). At St. 891, just south of the convergence on the way to Melbourne, we find the generation which must have resulted from this spawning in stage iii, and in the lower nets only. This, then, is the mid-winter spawning of the previous season's summer generation, and the population sampled at Sts. 887 and 891 consisted of the young over-wintering generation which, as we may conclude from what has gone before, will pass the winter mainly in stages iv and v below 250 m., and reappear at the surface in the spring. There is no evidence from the data available as to the limits within which the winter spawning took place, but it seems probable that it occurred throughout the entire range of the Antarctic waters, since young stages were found at St. 891, near the convergence, as well as at St. 887 at the edge of the pack-ice. The stock in the warmer Antarctic waters (St. 891) appears to have spawned earlier than that at St. 887, at the pack-ice edge, having reached stage iii by the end of May while that at St. 887 was only in stage ii. This, however, is what we might expect from our observations in the Falkland Sector during the summer.

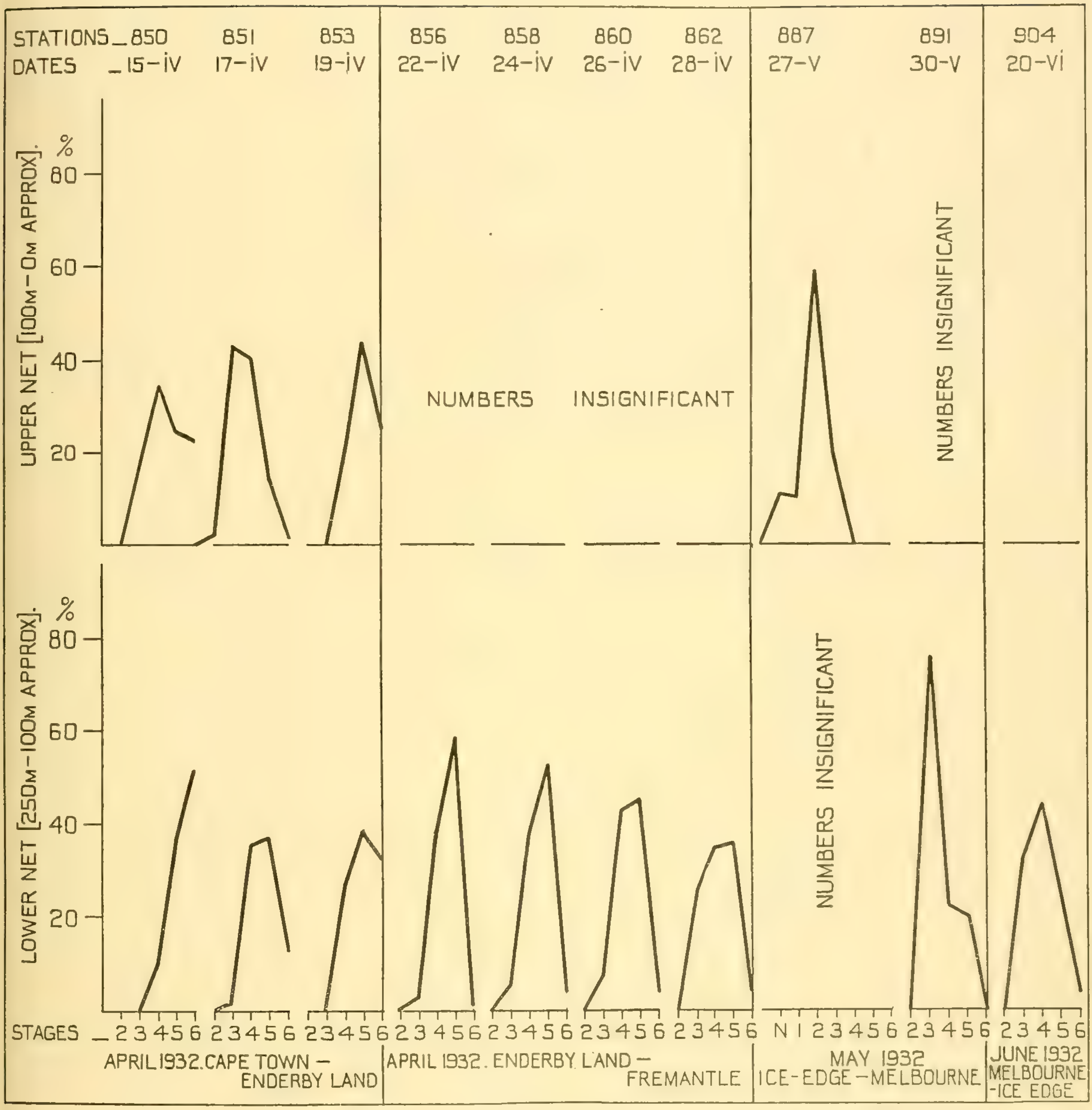

Fig. 25. Percentage of copepodite stages of *Rhincalanus gigas* in 1-m. nets. South Indian Ocean and Australian Sector. Winter months, April, May, June 1932. (See Table VI *e*.)

At the station just south of the Antarctic convergence (St. 904) nearly a month (20. vi) later than the stations above mentioned, on the line southwards from Melbourne, we find the winter generation largely advanced to stage iv, though many stage iii were still present.

There are certain striking features noticeable in the analyses of the stock in these winter months. One of these is the complete absence of adults from the catches after the middle of April. Adults were almost entirely absent from the catches on the line from Enderby Land to Fremantle at the end of April, when one would suppose that the summer generation was approaching maturity and was about to spawn. They were similarly quite absent in May, south of Australia, after spawning had taken place. As already remarked, a study of the stations taken in April on the Cape Town to Enderby Land line leads one to believe, though the evidence is admittedly slender, that the adults descend from the surface towards the winter level earlier than the younger copepodite stages (cf. upper and lower nets at Sts. 850 and 851, Fig. 25). One must assume that the adults have sunk beyond the range of these nets by the end of April, while the younger stages remain still within their range. It is hardly possible therefore to regard the hauls on these two lines as representative of the populations in these areas. The second striking feature of the catches during the winter was the swarm of very young stages near the surface at the end of May at the edge of the pack-ice (St. 887), since elsewhere at the same time of year small catches were being taken which appeared in the lower nets only. It seems probable that the explanation of this lies in the peculiar hydrological conditions existing at St. 887. This station was situated in the divergence region (Deacon, 1936) exactly upon the boundary between the East and West Wind Drift currents, where, owing to upwelling and mixing, warm deep water is carried up to within 60 m. of the surface. It seems certain, from the position of the main mass of the population at this time of year, at stations other than 887, that the winter spawning during May took place below the 250-m. level in southward-flowing warm deep water, out of range of the 250–100 m. net, but that at St. 887, near the edge of the ice, the young forms were carried upward to within 100 m. of the surface in the upwelling warm water. This is confirmed by the presence of stage iii in the lower net at St. 891, at almost the same date, away from the divergence region, and of stages iii and iv in a similar position about a month later.

SUMMARY, SOUTH INDIAN OCEAN AND AUSTRALIAN SECTOR, WINTER MONTHS 1932

1. In the South Indian Ocean the summer spawning in the season 1931–2 apparently took place later than in the Falkland Sector.

2. The mid-winter spawning in the Australian Sector in 1932 took place during May and the beginning of June. The winter generation was found in stage iii at the end of May and stage iv in the middle of June in northern Antarctic waters.

3. The winter spawning took place in southward-flowing warm deep water, but the young products were found at one station (887), taken at the edge of the pack-ice,

carried up towards the surface in upwelling warm deep water in the divergence region between the East and West Wind Drift currents.

4. Adults were absent from the catches after the end of April and had, after that time, presumably sunk out of reach of the 250–100 m. net.

Drake Passage, October to mid-November 1932 (Fig. 26, Table VI *f*)

When *Rhincalanus gigas* reappeared in the catches in October 1932 on the line of stations across the western end of the Drake Passage (Sts. 984–95) we find a remarkably high proportion of adults in the catches. This is particularly noticeable in the lower hauls at stations north of the convergence. In the upper nets a high proportion of stages iv and v was present at each of the three stations north of the convergence, while the catches in the lower nets at these stations were composed almost entirely of adults. This might perhaps suggest that the younger stages rise to the surface earlier in the season than the adults. At St. 978, at the beginning of October, we find a high proportion of stage iii in the upper nets but the catch was too small to give a reliable estimate of the population. The population generally seems to be in a much more advanced condition than in November 1931 in this same region. On the other hand at Sts. 1015, 1019 and 1021, about a fortnight later at the eastern end of the Drake Passage, the population consisted of stages v and vi (adults) and was thus in the same condition as at the end of November 1931 in this area. This must be due to the growth of stage iv into stage v in the fortnight intervening between these two north to south lines (Sts. 984–95, 1015 and 1019). On the evidence available it is not possible to speculate much on the condition of the population at the western end of the Drake Passage in October 1932. The stages iv and v certainly belong to the winter-spawned generation, and the condition of the ovaries (p. 318) indicates that the adults do also, since they were all "unripe" or "maturing". Evidently a higher proportion of the winter-spawned generation had reached the adult condition by the spring of 1932–3 than was the case in 1931–2. Comparison of the isotherm maps (Figs. 5 and 6) shows that the 2 and 3° isotherms occupied a more southerly position in October 1932 than in November 1931. It has already been remarked that the season 1931–2 was colder and later than 1932–3 in the South Georgia region, and the same appears to have been true in the Drake Passage also. This may perhaps account for the comparatively advanced condition of the overwintered *Rhincalanus* population in October 1932 as compared with its condition in November 1931. The population, as was found in November 1931, seems to have advanced farther in development north of the convergence than south of it, but there is no appearance of stage iii in the coldest water such as occurred at Sts. 735 and 737.

Scotia Sea and South Atlantic Ocean, mid-November to mid-December 1932 (Fig. 27, Table VI *g*)

At Sts. 1015, 1019 and 1021, in the western Scotia Sea and in sub-Antarctic water near the Falklands, we find the population in stages v and vi in the same condition as in

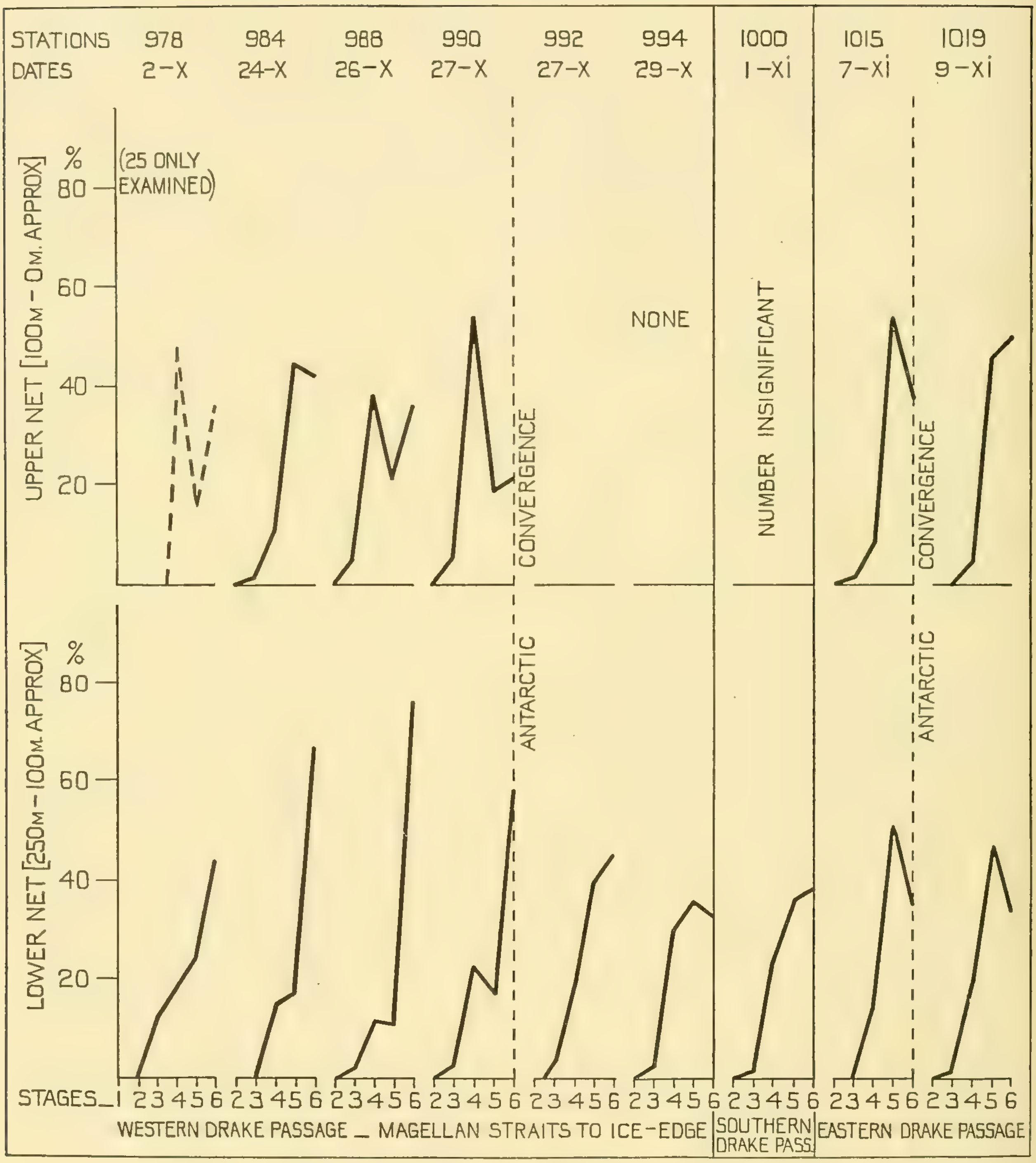

Fig. 26. Percentage of copepodite stages of *Rhincalanus gigas* in 1-m. nets. Drake Passage, October to mid-November 1932. (See Table VI *f*.)

November 1931 in this region; but from the middle of November (St. 1031) to the end of December (St. 1085) we find everywhere a mature stock consisting entirely of adults, with a few stage v—usually less than 20 per cent.

Some of the stations, for which the stock curves are shown in Fig. 27, were taken in Weddell Sea water (Sts. 1029, 1031, 1033, 1048, 1050, 1052, 1073, 1076 and 1085, Fig. 2 *a*). The remainder, except 1021 in South Atlantic water near the Falklands, were taken in the Bellingshausen Sea current (1054, 1056, 1063, 1066 and 1083, Fig. 2 *a*). Sts. 1029, 1052, 1073, 1076 and 1085 were taken in the "oldest" type of Weddell Sea water (average of 0–100 m. between 0 and 1·0° C.).

At Sts. 1029, 1052 and 1085, in the "oldest" Weddell Sea water, we find a high proportion of stage v in the upper nets, and, while the lower haul at St. 1029 was not analysed into stages, the lower hauls at Sts. 1052 and 1085 consisted of adults with some stage v, less than 25 per cent. At St. 1052, and to a lesser extent 1076, the proportion of adult males in the lower nets was high, and at these stations it is probably correct to assume that the population was a mixture of the populations of the Bellingshausen Sea current and the Weddell Sea current. St. 1073 was a shallow inshore station at which only a surface haul was made. It is apparent, however, that in this season, as in the previous one, the stock in the "oldest" Weddell Sea water is not yet mature, while it has reached maturity at stations in the Bellingshausen Sea current proper. This is shown by the high proportion of stage v in the population at Sts. 1029, 1052 and 1085. One must again assume that something has occurred to prevent that part of the stock originating in the Bellingshausen Sea current from attaining maturity, and that the action of water colder than 1·0° C. has possibly been to retard the development of the stages.

Sts. 1031, 1033, 1041, 1045, 1048 and 1050 were taken in Weddell Sea water of which the average temperature was less than 0° C., that is water carrying unmelted or melting pack-ice or water in which ice had recently melted. The population at St. 1033 is perhaps again a mixture of the Bellingshausen Sea and Weddell Sea stock, and here the proportion of adult males in the lower nets is rather high (13·8 per cent). At the other stations the stock is probably purely of Weddell Sea origin. At Sts. 1041 and 1045 the catches of *Rhincalanus* were too small for satisfactory analysis into stages and the copepod fauna at these stations was made up of species other than *R. gigas*, mainly *Calanus acutus* and *C. propinquus*. Sts. 1031, 1048 and 1050, however, show a mature population which consisted of adults and a few stage v, as was found in this type of water in the previous season (January 1932). This, if our conclusions drawn from the stock curves of the previous season are correct, is a population which has failed to spawn and which originated outside the Weddell Sea, possibly from the previous winter's spawning. It was carried into the Weddell Sea in the warm deep water of the East Wind Drift current, and has risen from the deep water into the surface water during its passage through the Weddell Sea in the north-easterly current.

With regard to the appearance of males during this season, we have already seen that the proportion of adult males was high at Sts. 1052 and 1076 in the "oldest" type

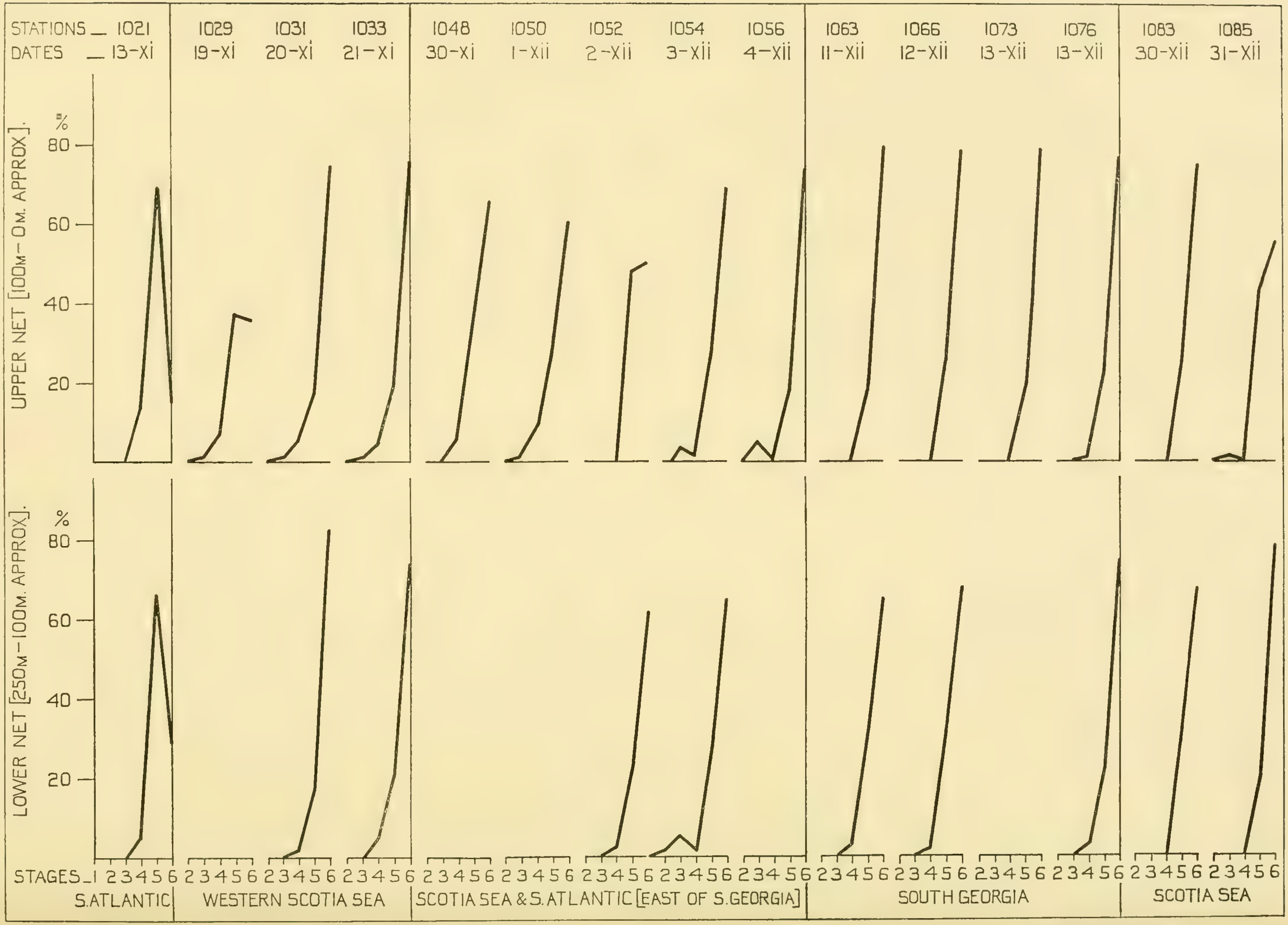

Fig. 27. Percentage of copepodite stages of *Rhincalanus gigas* in 1-m. nets. Scotia Sea and South Atlantic Ocean, December 1932. (See Table VI *g*.)

of Weddell Sea water, where the stock is probably of mixed origin. It was also high at stations in the Bellingshausen Sea current proper from the middle of November to the end of December (Sts. 1021, 1054, 1063, 1066, 1083, see Table V *b*). A high proportion of adult males was thus found in the catches from the middle of November to the end of December in the season 1932–3, instead of from the middle of December to the end of that month as in the season 1931–2 (see p. 320, Table V *a* and Fig. 18). Since there were no observations for January 1933 it is not possible to decide exactly when the catches ceased to contain a high percentage of adult males during that season.

Thus, in the season 1932–3, we find the stock of *Rhincalanus* reaching maturity from the end of November and throughout December in the Bellingshausen Sea current, and adult males appearing in the catches at the same time. Adult males therefore appeared slightly earlier than in the previous season and the population became mature slightly earlier also. In 1931–2 the first station at which a mature stock was found was St. 763 (8. xii. 31), which was in Weddell Sea water, while at Sts. 774 and 775 (16. xii. 31) in the Bellingshausen Sea current itself there was still a high proportion of stage v in the catches. In 1932–3 the first station at which a mature stock was found was St. 1031 (20. xi. 32) in Weddell Sea water and the first in the Bellingshausen Sea current was St. 1054 (3. xii. 32). It may therefore be assumed that, since maturity was reached at least a fortnight earlier and adult males made their appearance a month earlier, so also spawning probably began earlier in this season than in the preceding one. Throughout December, however, there was no appearance of nauplii or young stages such as would indicate the hatching of eggs. At Sts. 1054 and 1056, north of South Georgia (3. xii and 4. xii) there was a very small percentage of stage iii—5 per cent and less—but these hardly indicate that hatching had taken place recently or on an appreciable scale. It is possible that spawning never took place around South Georgia during the month of December on a scale large enough to produce a catch of nauplii in the 1-m. net.

During January 1933 the 'Discovery II' was engaged in making a running survey of the South Orkney Islands. During that month no plankton stations were taken, so that observations for the month of January 1933 are unfortunately lacking. At the end of that month and during the first week in February a number of plankton stations were taken in the Bransfield Straits (Sts. 1097–1110; Fig. 2 *b*). *R. gigas* was almost completely absent from this area, as was found at the end of October and the beginning of November. The next stations, therefore, at which samples of *Rhincalanus* large enough to be analysed were taken, are those worked in the Drake Passage at the end of the first week in February.

Drake Passage, early February 1933 (Fig. 28, Table VI *h*)

At the most southerly station (1115) in the Drake Passage there was a small catch in the lower nets only. The stock curve shows that it consisted of stages iv, v and vi. At St. 1116, the station to the north, the stock consisted of stages iv and v, without the high percentage of adults found at St. 1115. The latter station (1115) was situated just off the Antarctic continental shelf, in a position, again, where warm deep water wells

upwards from beneath the Antarctic surface layer. One may therefore expect that the stock of *Rhincalanus* taken in the lower nets at this station has been carried into this position in warm deep water from somewhere farther north. The stock at this station (1115) is, therefore, probably much the same as that at St. 1116, and it may be possible to explain the comparatively high percentage of adults at St. 1115 on the assumption that the autumn descent from the surface has already begun in this area (as it apparently has—see Fig. 12), and that, if adults sink into the warm deep water before the younger stages, as we have elsewhere supposed that they do (p. 340), a high proportion of adults may be expected in this water where it is found moving upwards as at St. 1115.

At Sts. 1116 and 1117 we see what is evidently the summer generation in an advanced state of development. At St. 1116 the population consisted of stages iv and v, with a small proportion of adults, and at St. 1117, farther north near the convergence, the population is considerably older and consisted of stages v and vi (adults). The spawning therefore which gave rise to the stock at St. 1117, in the warmer waters of the Drake Passage, must have taken place earlier in the year than that which gave rise to the stock at St. 1116, in the colder water. No deep hydrological observations were made at St. 1116, so that it is not possible to say with certainty whether it lies within the optimum range (an average of 1·0–4·0° C. for the 0–100-m. layer) of spawning or outside it. The surface temperature was 2·76° C., so that it seems probable that this station lay within these limits. It must be remembered, however, that the population sampled at this station in early February had drifted from considerably colder water farther to the south-west where the average temperature (Fig. 7) may have been lower than 1·0° C. At St. 1117 the average temperature was 4·11° C., but the population sampled at this station must again have drifted from the south-west where the temperature of the water was colder than this, though probably not colder than 1·0° C. (Fig. 7). The age of the stock at both these stations seems to point to an early spawning in these waters. In the season 1931–2 it was seen that spawning took place first in December east of South Georgia and later in the Scotia Sea and Drake Passage. In the season 1932–3 it has been suggested, from the time of appearance of a high proportion of males and of the attainment of maturity by the over-wintered generation, that spawning may have taken place earlier than in the previous season. The condition of the population at Sts. 1116 and 1117 in the Drake Passage in early February 1933 seems to confirm this suggestion, although it is evident from the stock curves at St. 1083 (stages v and vi; Fig. 27), south of South Georgia, that no spawning took place in the colder waters of the Scotia Sea before the end of December. As will be seen in the following section (p. 348) conditions at Sts. 1127 and 1131 also point to a later spawning in the Scotia Sea, as compared with the warmer waters farther west near the convergence.

Falkland Islands to South Georgia, February 1933 (Fig. 28, Table VI *h*)

The *Rhincalanus* population was analysed at five of the stations taken between the Falkland Islands and South Georgia in late February 1933.

On the Antarctic side of the convergence stages iii and iv predominated at the two

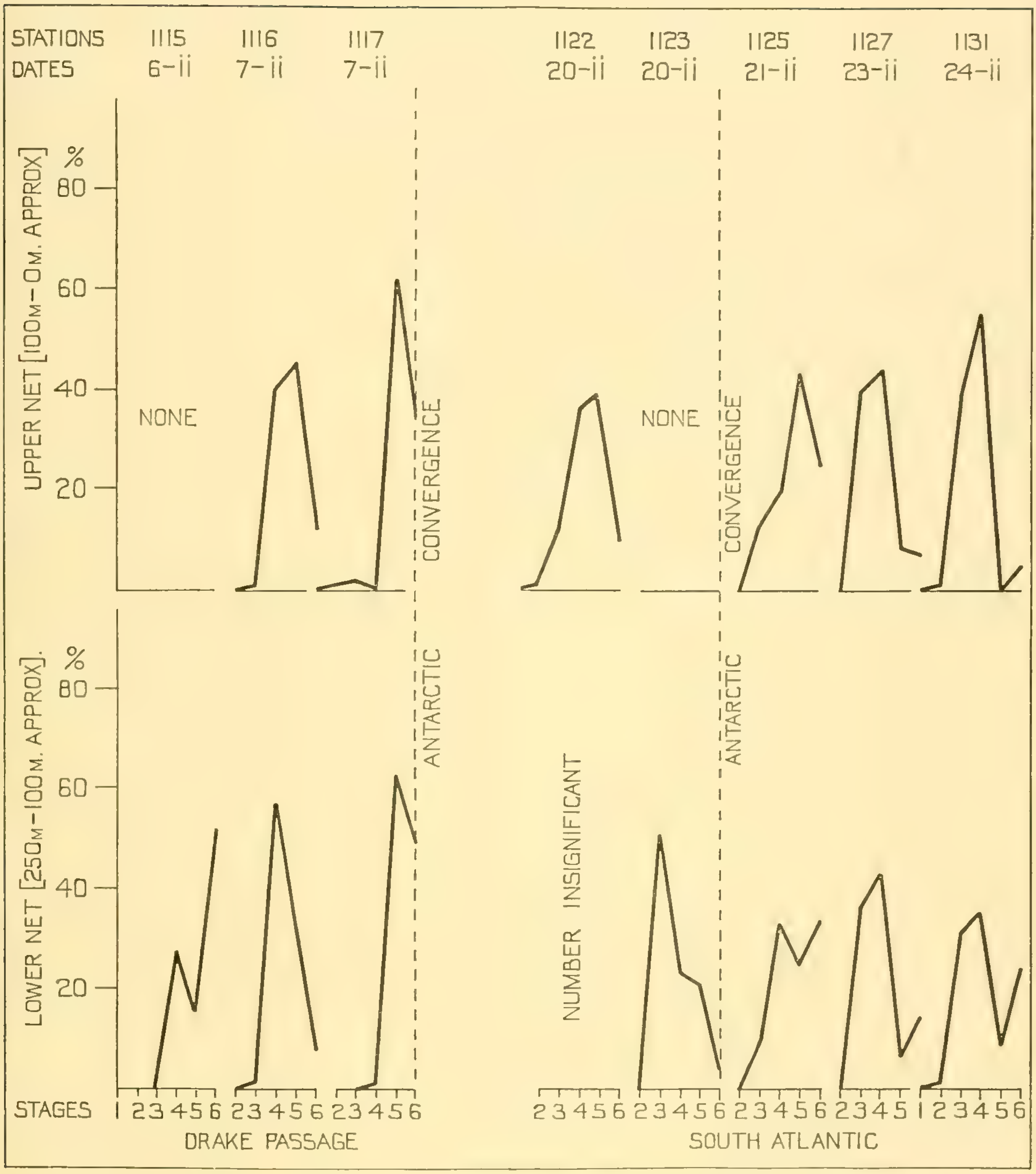

Fig. 28. Percentage of copepodite stages of *Rhincalanus gigas* in 1-m. nets. Drake Passage and South Atlantic Ocean, February 1933. (See Table VI *h*.)

stations near South Georgia (Sts. 1127 and 1131). At St. 1125, farther west near the convergence, the population was in stages iv, v and vi, together with some stage iii. At this station the adult females (see p. 318) were mostly unripe or maturing, and this population had evidently been spawned during the current summer. The average temperature at St. 1125 was 3·19° C., and the population in that area must have drifted from some position in the eastern Drake Passage or western Scotia Sea to the south-west. The spawning which, earlier in the summer, gave rise to the stock at this station must, therefore, have taken place in water having an average temperature probably lower than 3·0° C. but higher than 1·0° C. (Fig. 7). The population sampled at Sts. 1127 and 1131, however, consisting predominantly of stages iii and iv, must, from its age, have been spawned later than that at St. 1125. It probably originated in the western Scotia Sea in water having an average temperature considerably nearer the lower limit of the optimum spawning range (1·0° C.) than that in which the population at St. 1125 originated. Thus, again, spawning took place later in the colder water.

The stock sampled at St. 1125 (stages iv, v and vi) would appear to have been spawned at about the same time as that which was sampled at Sts. 1116 and 1117 in the Drake Passage (stages iv and v and v and vi respectively). The stock at Sts. 1127 and 1131, however (stages iii and iv), must have been spawned much later in the season, so that a southward, and possibly eastward, movement of the spawning area is discernible in the season 1932–3, as in the previous season, from the warmer to the colder Antarctic surface water of the Drake Passage and Scotia Sea.

The population at St. 1125 was older than that which was sampled at St. 830 in the same position in the preceding February (cf. Figs. 24 and 28) since it contained a higher proportion of adults and stage v and, taking both nets together, a smaller proportion of stage iii. This again confirms the suggestion that the spawning occurred earlier in the Bellingshausen Sea current in 1932–3 than in 1931–2. The stock at 1127 and 1131, on the other hand, farther east near South Georgia, is of the same age as that found in this region in February 1932 (St. 831; Fig. 24) so that these two populations, sampled in the South Georgia region at the same time in two succeeding seasons, may be judged to have resulted from spawnings which took place in the Scotia Sea at the same time of year in both seasons. In 1931–2 it was seen that the spawning east of South Georgia in the South Atlantic took place a good deal earlier than that which gave rise to the population at 831. Thus in both seasons the spawning seems to have moved southwards into the Scotia Sea from the South Atlantic and the Drake Passage; but while the spawning in the Drake Passage, and probably in the South Atlantic, took place earlier in 1932–3 than in 1931–2, it seems to have occurred at approximately the same time of year in both seasons in the Scotia Sea.

On the sub-Antarctic side of the Antarctic convergence, between the Falklands and South Georgia in February 1933, the two hauls large enough to be analysed, at Sts. 1122 and 1123, showed a population in stages iii, iv and v. The state of affairs at these two stations was possibly the same as that at Sts. 828 and 829 in the previous season, and the population sampled here may have been, perhaps, the product of a much reduced late

spawning, in sub-Antarctic water. The age of the stock suggests that it had resulted from a considerably later spawning than that which gave rise to the stock on the Antarctic side of the convergence (St. 1125).

Weddell Sea, March 1933 (Fig. 29, Table VI *i*)

During March a line of stations was taken from South Georgia to the pack-ice edge in 69° 22′ S and 9° 27·5′ E. The *Rhincalanus* population was analysed at six of these stations. Three of the stations, at which the catches were analysed into stages, were in water flowing north-eastwards out of the Weddell Sea towards the South Sandwich Islands as the Weddell Sea current (Sts. 1138, 1142 and 1144), and three were taken in the East Wind Drift current flowing westwards into the Weddell Sea along the coast of Coats Land (Sts. 1148, 1150 and 1152).

At the first group of stations, those in water flowing out of the Weddell Sea, the stock consisted mostly of stages iii and iv. St. 1138 was situated near the boundary between Weddell Sea water and water of Bellingshausen Sea origin. The average temperature was 0·76° C. ("oldest" Weddell Sea water), and it is therefore probable that the stock at this station contained a mixture of the populations of the Bellingshausen Sea current and of the Weddell Sea current. We saw that at St. 1131, a little over a week earlier near South Georgia, the population also consisted of stages iii and iv, so that the probability is that the same population was sampled at both these stations. At St. 1142, where the catch occurred only in the lower net, the stock consisted almost entirely of stage iv. The temperatures of the surface 200 m. at this station show that it was worked in a tongue of warm water moving south from the north (Deacon, 1936), so that the stock found in the lower nets probably originated in the South Atlantic. It is very similar in its constitution to that at Sts. 1138 and 1131, and it thus seems extremely probable that the populations sampled at Sts. 1138 and 1142 are similar in origin and are carried into the Weddell Sea by warm deep water from the South Atlantic. At St. 1144 there is a northerly movement at the surface and a southerly movement from the Atlantic in the lower levels, which is strongest at about 400 m. (Deacon, 1936). This southerly movement, however, is less perceptible at St. 1144 than at St. 1142. The catches of *Rhincalanus* at St. 1144 were small, but it will be seen from Fig. 29 that the stock in the upper net, in water with a northward tendency, was younger (stages iii and iv) than that in the lower net (mainly stage v) which may be expected to have a mixed origin, part of the stock, at least, having been carried southward in the lower layers. It will be noticed that the population sampled by the lower net was similar in constitution to that found at the following stations (Sts. 1148, 1150 and 1152) in the East Wind Drift current. The catch taken by the upper net was too small for any definite conclusion to be drawn, but its age was the same as that of the population sampled at the preceding stations (1138 and 1142). It may be that it belongs to the same stock but, alternatively, it might perhaps suggest that a spawning had taken place in Weddell Sea water very much later in the year than in the Bellingshausen Sea current. On this point, however, the evidence is at present insufficient.

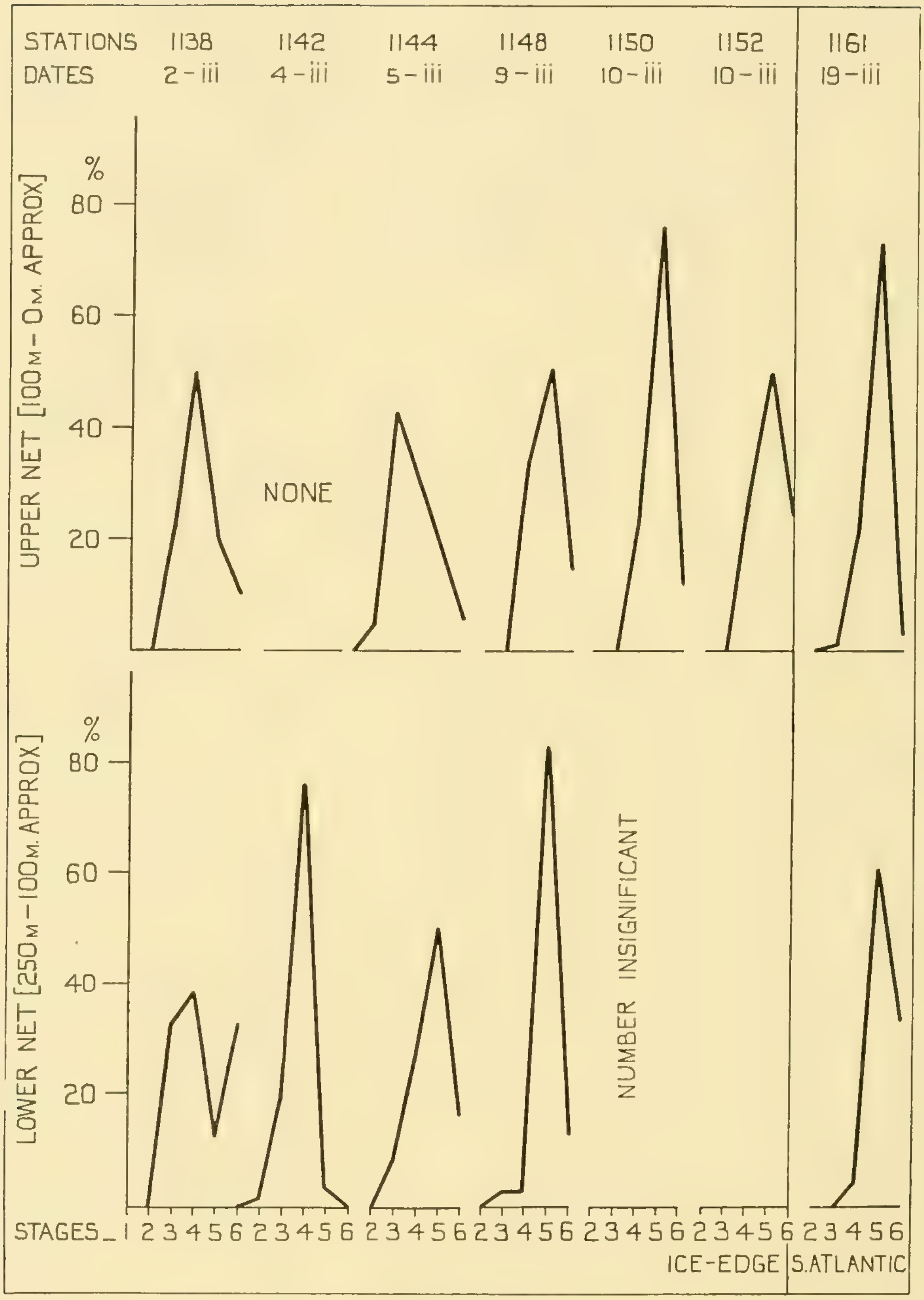

Fig. 29. Percentage of copepodite stages of *Rhincalanus gigas* in 1-m. nets. Weddell Sea, March 1933. (See Table VI *i*.)

At Sts. 1148, 1150 and 1152, in the East Wind Drift current, we find a population, spawned in South Atlantic water to the east, probably in the middle of summer. This is a population which corresponds with that found in January 1932 at Sts. 816 and 817 in stage iv (p. 332). The fact that in March 1933, farther east, it was found only as far advanced as stage v points to a somewhat later spawning of this stock than was indicated in the previous season.

The 1-m. net was used at one station on the line from the ice edge to South Africa at the end of March 1933. This station (1161) was taken just south of the convergence between the pack-ice edge in the Weddell Sea and South Africa. A summer generation was found here in stage v, with adults in the lower net. The majority of the catch was in the lower net.

SUMMARY, FALKLAND SECTOR, SEASON 1932–3

1. The over-wintered stock appeared within the range of the nets at the end of October 1932 in stages iv, v and vi. Stage vi (adults) were particularly abundant north of the convergence (p. 341).

2. In the eastern Drake Passage and western Scotia Sea the population in November was in stages v and vi. From the end of November until the end of December the stock was everywhere mature in water of Bellingshausen Sea origin (p. 345).

3. In the "oldest" water of Weddell Sea origin at the end of November and beginning of December the population was in stage v, while at stations in Weddell Sea water with an average temperature below 0° C. the stock consisted of adults with no young stages. The population in the "oldest" Weddell Sea water (0–1·0° C.) is presumed to have a mixed origin and to belong partly to the Weddell Sea current and partly to the Bellingshausen Sea current. Thus, as in the previous season, the part of the population which belonged to the Bellingshausen Sea current had apparently failed to reach maturity at the same time as the stock in the Bellingshausen Sea itself (p. 343).

4. Spawning in the South Georgia region is thought to have taken place earlier in the season 1932–3 than in 1931–2, in view of the earlier attainment of maturity by the population and the earlier appearance of adult males. Spawning was not apparent from the catches, however, during December, and there were no observations for January (p. 345).

5. In the Drake Passage in February a summer generation in stages iv and v was found in the colder waters. In the warmer waters there was an older summer stock in stages v and vi. It was concluded from this that spawning had taken place earlier in the warmer Antarctic waters near the convergence than in the colder Antarctic waters farther south. (p. 346).

6. Between the Falklands and South Georgia in the second half of February two different stocks were again found in Antarctic waters—a younger one in stages iii and iv in the colder water near South Georgia and an older one in stages iv, v and vi in warmer water farther west near the convergence (p. 348).

7. In the Weddell Sea in March, again, two different stocks were found. In water

flowing out of the Weddell Sea there was a population in stages iii and iv, and in water flowing into the Weddell Sea as the East Wind Drift current, south of 66° S, there was a population in stage v. One station (1142) was taken in a tongue of water flowing southwards from the South Atlantic. Here the *Rhincalanus* population was in stage iv. It is presumed that the stock at this station and at those on this line taken in water flowing out of the Weddell Sea owes its origin to the South Atlantic deep water (p. 349).

8. It would appear that in the season 1932–3 spawning began in the warmer Antarctic water near the convergence perhaps at the beginning of December near South Georgia, but possibly earlier than this farther west in the Drake Passage, and later spread southwards into the Scotia Sea. It is thus possible to state that there must be a movement southwards of the spawning area from the convergence into colder Antarctic water as the summer advances (pp. 345–8).

COMPARISON OF SEASONS 1931–2 AND 1932–3, FALKLAND SECTOR

In the first half of both seasons, 1931–2 and 1932–3, the area of maximum abundance of *Rhincalanus gigas* lay in the Drake Passage, Western Scotia Sea and South Atlantic, and the area of greatest scarcity in the Weddell Sea and in water of Weddell Sea origin. In the first half of 1931–2 the region of greatest abundance, in which more than 10,000 individuals were taken at all stations, occupied Antarctic water of Bellingshausen Sea origin over a wide area in the Falkland Sector from the western Drake Passage to the South Atlantic. In the early part of the second season, 1932–3, however, this region was restricted to a comparatively small area between South Georgia and the Falkland Islands. This was perhaps in part due to the fact that the waters of the Drake Passage were investigated nearly a month earlier than in the previous season, so that the main mass of the population was still out of range of the nets. Between the Falklands and South Georgia in February much the same conditions were found in both seasons. The catches were fairly large on the Antarctic side of the convergence but smaller than they were in this area earlier in the year, in November and December. On the sub-Antarctic side of the convergence a very marked reduction in the catches was found during February in both seasons. This may either be due to the fact that the winter descent from the surface strata takes place earlier north of the convergence in sub-Antarctic water than south of it in Antarctic water, or, more probably, to the reduction of the summer spawning in the sub-Antarctic so that the over-wintered generation in those waters dies out after mid-summer and is replaced by a greatly diminished summer generation.

In 1931–2, in the Bellingshausen Sea current, the ascent from the winter level to the surface apparently took place more irregularly and over a longer period than in 1932–3. During the latter season the majority of the catches appeared in the upper nets from the beginning of November onwards until February. In 1931–2, however, the figures suggest that the ascent to the surface began near the convergence in November, but that at stations away from the convergence it did not appear to have taken place until the middle of December. In water of Weddell Sea origin in both seasons the catches were

usually in the upper nets in all but the "oldest" type of water (0–1·0° C.). No observations were made in the South Atlantic water east of the South Sandwich Islands during the second season comparable with those taken in January 1932.

In 1931–2 the population in waters of Bellingshausen Sea origin around South Georgia and in the Scotia Sea came to maturity in the middle of December, and males appeared in the lower hauls in increased numbers at the same time of year. Nauplii were taken at one station in the South Atlantic, in Antarctic surface water of Bellingshausen Sea origin, on the eighteenth of December. At the end of the first week in January, in the same water, an advancing summer generation was found in stage iii. Spawning evidently began in the middle of December and possibly continued throughout that month in Antarctic surface water of the South Atlantic east of South Georgia. Spawning and hatching of the eggs apparently took place within a very short time. In 1932–3, however, the population in the Scotia Sea and around South Georgia was found to be mature at the end of November, and males began to increase in the catches at the same time. The maximum number of males appeared at the beginning of December during this season, as against the middle of that month in 1931–2. It is, therefore, justifiable to suppose that spawning began correspondingly earlier—a fortnight or three weeks—in 1932–3 than in 1931–2 in the waters around South Georgia. The condition of the summer generation in the Drake Passage in early February (stages iv, v and vi) confirms this supposition.

Comparison of the isotherm charts for the seasons 1931–2 and 1932–3 (Figs. 5, 6) shows that the former was a colder and "later" season than the latter. In the spring of 1932–3 the isotherms for 1·0° C. and over occupied a more southerly mean position than in the spring of 1931–2. This is less true of the isotherms for 0° C. and temperatures below 0°. Warm water, therefore, extended farther south at the beginning of 1932–3 than at the beginning of 1931–2 and the transition from warm to cold water from lower to higher latitudes was correspondingly more abrupt. The pack ice also was farther north in 1931–2 than in 1932–3. In the Drake Passage at the end of November 1931 the pack ice was met with in about 64° S. (St. 735) and was followed through the Drake Passage to about 60° S. (St. 741) where it trended away southwards. It thus lay far to the north of the South Shetlands. It was met with again near the South Orkneys at the beginning of December and was again followed north-eastward to about 57° S. (St. 767) in the longitude of South Georgia. At the end of October 1932, however, the pack ice was met with in 67° S. in the western Drake Passage (St. 995) and the Bransfield Straits were entirely free during early November. At the end of that month the ice was followed from about 62° S. in the longitude of the South Orkneys (St. 1035) north-eastwards to about 58° 30′ S. (St. 1045, between Bristol and Montague Islands) in the South Sandwich group. Thus appearances strongly suggest that the difference in the spawning time of *R. gigas* in the two seasons may be connected with these differences of temperature and ice conditions.

In 1931–2 no spawning at all took place in Weddell Sea water, at least before the end of January; but the line taken from South Georgia through the waters of the Weddell

Sea in March 1933 might perhaps suggest that some degree of spawning may take place in the warmer water of Weddell Sea origin much later in the season than the main spawning in waters of Bellingshausen Sea origin. The station in question here, however, certainly does not provide sufficient evidence for a statement on this point.

In both seasons, between the Falklands and South Georgia, a similar state of affairs was found—a maturing summer generation in warm Antarctic water near the convergence and a younger generation in colder water near South Georgia. Similarly in the Drake Passage in February 1933 the summer generation was found to be much older in warmer Antarctic water than in colder water farther south. Appearances suggest that in both seasons spawning took place later in the colder than in the warmer Antarctic water. In 1931–2 it took place later in the Scotia Sea, south-west of South Georgia (St. 825), than in South Atlantic water east of the island, and further the stock spawned in the Scotia Sea was found in February of both seasons, between the Falklands and South Georgia, to be of the same age, so that the presumption is that spawning occurred at roughly the same time in the Scotia Sea in both years. In the season 1931–2 spawning began in early December in the South Atlantic, in water of Bellingshausen Sea origin, east of South Georgia and spread later into the Scotia Sea. In 1932–3 there is also evidence that spawning took place first in the warmer Antarctic water and later spread into the colder waters of the Scotia Sea, and in the Drake Passage in this season there is evidence of a similar movement of the spawning southwards from warmer into colder water. There is thus discernible in both seasons a trend of the spawning southward as the summer advances.

DISCUSSION

The conditions revealed by the stock curves for the latter half of the seasons 1931–2 and 1932–3 do not admit of any straightforward explanation. We saw that in the Antarctic water flowing northwards from the Drake Passage and Bellingshausen Sea the *Rhincalanus* population came to maturity in late November or in December around South Georgia. Adult males appeared in the lower nets at that time, and one may assume that the main spawning occurred then. It is evident, however, that during both seasons a number of different populations was sampled having different ages in different regions, even when allowance has been made for patching and swarming and for the inaccuracies of the type of net employed.

In the season 1931–2, at least three age groups were found east of South Georgia in January. In Bellingshausen Sea water, in the South Atlantic Ocean, there was an advancing summer generation. In Weddell Sea water of a certain temperature (between 0 and 1·0° C.) there was a population mainly in copepodite stage v, which was presumed to have been carried southward in the Atlantic warm deep water, and in Weddell Sea water with a temperature below 0° C. there was a population consisting almost entirely of adults. At the end of January 1932 a station (825) near the boundary between Weddell Sea and Bellingshausen Sea water near South Georgia showed a population

of the same age as the advancing summer generation sampled three weeks earlier in the South Atlantic.

In the southern Drake Passage in early February 1933 a half-grown summer generation was found, while in the more northerly Antarctic water in the Drake Passage, near the convergence, there was a still older summer generation. Between the Falklands and South Georgia in February the conditions were remarkably similar in the two seasons (1931–2 and 1932–3). In both seasons in Antarctic water near the convergence (Sts. 830 and 1125) a summer generation was found approaching maturity, while near South Georgia, in colder water, the summer generation was found to be much younger (Sts. 831, 1127 and 1131).

In Weddell Sea water in March 1933 two apparent age groups were found—a half-grown summer generation in water flowing out of the Weddell Sea in a north-easterly direction and a slightly older generation in water flowing into the Weddell Sea in a westerly direction south of 66° S.

Again in the Australian Sector during the winter great numbers of nauplii and very young stages were taken near the ice, while at the same time of year a very much older winter-spawned generation was found at the northern Antarctic stations between Australia and the ice edge. When the over-wintered generation reappeared at the surface in the spring of 1932–3 in the Drake Passage it was found to be in a more advanced condition than the over-wintered generation which was found a month later in the same region the year before, when the temperature of the water was lower. In November 1931 there was a pronounced difference between the age of the overwintered generation in warm Antarctic water and its age in the cold water near the ice edge.

In order to explain the large number of apparently different age groups in different localities in the Falkland Sector and elsewhere, we have suggested, tentatively, that the main spawning takes place within a certain sea-temperature range. This range appears to lie between the temperatures 1·0 and 4·0° C. Temperatures below this range have everywhere a similar effect upon the *Rhincalanus* population—growth and development are retarded and spawning is thus delayed. Outside certain wider temperature limits the spawning is stopped altogether. It is not possible to decide at present where these wider limits lie, but appearances in the Weddell Sea suggest that the lower limit might be between 0 and − 1·0° C. The effect of temperatures higher than 4·0° C. also seems to be to inhibit spawning, since very little spawning appears to take place in sub-Antarctic water.

The dependence of the breeding of marine animals upon constant optimum temperature limits has been demonstrated and discussed by Orton (1920) and Runnström (1927). Orton wrote (p. 362): "Temperature limits seem to influence breeding in various ways which appear to be dependent upon the limitation of the breeding period by apparently constant maximum and/or minimum temperatures. These temperatures appear to be physiological constants for the species." Runnström showed that these relationships between breeding and temperature have a direct bearing on the geographical distribution of the species.

Now in the Falkland Sector of the Antarctic, as already seen (p. 292), there was, in the season 1932–3, a southward movement of the isotherms towards the end of the summer. This was more marked for the lower temperatures below the 3·0° C. isotherm than for higher temperatures, and it was especially pronounced in the Weddell Sea area, south and south-east of South Georgia (Figs. 6, 7). This, in all probability, is due to the break-up of the pack-ice as the season advances. The region of optimum temperature (1·0–4·0° C.) for the spawning of *Rhincalanus* thus extends itself southwards towards the end of the summer, and there is every reason to believe that this is a phenomenon of yearly occurrence, accompanied by the replacement of a "cold-water" plankton by a "warm-water" one in higher latitudes towards the end of the season (Mackintosh, 1934). This would then provide an explanation of the late summer spawning of *Rhincalanus* in the higher latitudes and of the general southward movement of the spawning area, for the stock in water which is below the optimum temperature limit will not spawn until either it has drifted into warmer water within the spawning range or the water itself has been raised to within the limits by the seasonal increase in temperature, consequent upon the southward movement of the isotherms. In this manner, therefore, the spawning time may be related to the break-up of the pack-ice. The correlation between the time of spawning of *R. gigas* and the position of the pack-ice, as already mentioned, further suggests that ice conditions, through their influence upon the temperature of Antarctic seas, are the governing factor in determining the spawning of this species.[1]

We have suggested, in connection with the delay of the spawning time of *Rhincalanus* in colder waters, that the relationship of the temperature to growth, that is to development, is a factor of the greatest importance, and that in colder waters the spawning time is delayed by the retardation of the attainment of maturity in the parent generation.

We have seen that in Weddell Sea water having an average temperature for 0–100 m. between 0 and 1·0° C. the *Rhincalanus* population in January 1932 had only reached copepodite stage v in development (p. 330), while at stations in South Atlantic water where the temperature of the surface 100 m. was above 1·0° C. the population had spawned and hatched eggs. Thus over-wintered forms which drift into Weddell Sea water having a temperature below 1·0° C. fail to reach the adult stage by midsummer.

[1] Since this report went to press a paper by Ottestad (1936) has appeared dealing with the biology of four species of Antarctic copepod (*Calanus acutus*, *C. propinquus*, *Rhincalanus gigas* and *Metridia gerlachei*) from the collections of the Norvegia Expedition. The author found a relationship between the composition of the stock in stages and the temperature of the surface layers in *C. acutus*, *C. propinquus* and, to a lesser extent, *M. gerlachei*. He related the spawning of these species to the break up of the pack-ice, and concluded that as the older individuals drift northwards into water uncovered by pack-ice they "mature and commence to spawn" (p. 23). He found no such relationship, however, in *R. gigas* and concluded that "there must be a fundamental difference in the life histories of the two species" (*C. acutus* and *R. gigas*, p. 28), and that *R. gigas*, must be a native of sub-Antarctic waters. The conclusions of Ottestad for *C. acutus* and *C. propinquus* are similar to those which we have reached, independently and with more abundant material, for *R. gigas*. The two former species evidently spawn when the temperature of the water in which they are carried reaches a certain optimum, which lies within lower limits for these species than for *R. gigas*.

We also noted that in November 1931 in the Drake Passage (p. 324) the over-wintered population in warm sub-Antarctic water consisted mostly of adults, while that in Antarctic water, south of the convergence, consisted mostly of stages iv and v. In the coldest Antarctic water (− 1·5° C.) comparatively large numbers of stage iii were taken. Evidently, young stages which developed during the winter in the coldest Antarctic water only reached stages iii and iv by the spring, while those which developed in warmer Antarctic water reached stages iv and v. The same age difference, although less marked, was also found in October 1932 in the Drake Passage (p. 341). All the above facts can be explained on the assumption that, as there is an optimum temperature range for spawning, so also there is an optimum temperature range for growth and development, and that temperatures which approach the lower limit of that range slow up the development. The limits of this range cannot be exactly fixed in the present work, but they do not seem to be widely different from those of the optimum spawning range, and it would appear that an appreciable slowing up of the rate of development of the population is to be found in water with an average temperature for the 0–100-m. layer below 1·0° C.

That reduction of temperature does have a retarding effect upon the development of some marine animals is well known. Murray and Hjort (1912, p. 555) quote the lobster, whose eggs and larvae are only developed during the warmest part of the year, "and it has been found that a fall of a few degrees is sufficient to retard the development for several weeks". Gran (1902) explained the different ages of the stocks of *Calanus finmarchicus* in the Norwegian Seas (p. 62) by assuming that "the yearly developmental cycle is disarranged through the influence of outside factors, especially temperature", and, again, that "the length of life will differ in different regions. External factors can act upon the rate of development and thus on the length of life" (p. 64).

In this connection it is perhaps permissible to mention the results of Coker (1933), who experimented with two species of *Cyclops*. One of these, when kept at room temperature, spent a disproportionately long time in a state of arrested development at stage iv. It could be made to develop normally, without any arrested stage iv, by being placed in a refrigerator. Moreover, eggs hatched at room temperature mostly failed to develop, and those which did so developed slowly and remained at stage iv for 120–140 days, a period corresponding to the theoretical duration of several cycles of development. Another species, on the other hand, developed exactly seven times more rapidly at room temperature than in the refrigerator. Thus while one species passed through its development normally at a low temperature (about 8° C.) a higher temperature (about 22° C.) slowed down development. The other species behaved in an exactly opposite way and developed normally at the higher temperatures but was retarded at the lower. Runnström (1929) determined the optimum range for the development of littoral Mediterranean-boreal forms, but his tabulated results show in every case that temperatures as little as half a degree above or below the optimum range for the species had the effect not of retarding development but of preventing it altogether. The eggs failed to segment, or segmented irregularly and died, or reached early embryonic stages and then died.

At present we can do no more than suggest that delayed spawning may be due to the failure of the parent generation to reach maturity by the normal spawning time, owing to external conditions such as temperature unfavourable to growth.

GENERAL SUMMARY

1. The foregoing paper is an account of the horizontal, and as far as possible the vertical, distribution of the species *Rhincalanus gigas* (Brady) in the Falkland Sector of the Antarctic during the summer seasons 1931–2 and 1932–3, and during the winter months of the year 1932 around the Antarctic Continent. Some account of the life history of the species, as far as it can be judged from the data available, has also been given. The material upon which the paper is based consists of the catches from a large number of hauls made with the 1-m. stramin net in the Falkland Sector of the Antarctic and around the Antarctic Continent during the 1931–3 commission of the R.R.S. 'Discovery II'. At every station from which the catches were analysed in this work the 1-m. net was towed from 250 to 100 m. approximately and from approximately 100 m. to the surface.

2. *Rhincalanus gigas* is the dominant species in the copepod macroplankton, and thus in the macroplankton generally, throughout a wide area of the Falkland Sector of the Antarctic. In the season 1931–2 it constituted over 75 per cent of the copepod catches in Antarctic water flowing north-eastwards from the Bellingshausen Sea, around the west coast of South Georgia, into the South Atlantic Ocean. In this water during the season 1931–2 over 10,000 individuals were taken in the upper and lower of the two towings together. In the season 1932–3 the catches were smaller, and over 10,000 individuals were only taken at two stations, one in the Bellingshausen Sea current and one in sub-Antarctic water between the Falklands and South Georgia. At the remaining station the catches usually amounted to between 5000 and 10,000 individuals. *R. gigas* constituted more than 75 % of the copepod catches in both Antarctic and sub-Antarctic water in the Drake Passage in the season 1932–3 (pp. 294, 308, 313).

3. The Weddell Sea is an area of scarcity of *R. gigas*, contrasting sharply with the area of abundance in water of Bellingshausen Sea origin. In 1931 2 *R. gigas* amounted to less than 15 per cent of the total catch in Weddell Sea water where the average temperature of the surface 100 m. was less than 0° C. (p. 296). In the season 1932–3 this species formed less than 25 per cent in Weddell Sea water, of which the average temperature of the surface 100 m. was less than 0° C. and less than 15 per cent in water with a temperature less than – 1·0° C. (p. 313). In both seasons the total catches in Weddell Sea water with a temperature below – 1·0° C. amounted to less than 500 individuals in both nets.

4. During the summer months the species extended north of the Antarctic convergence in the Falkland Sector, but in the winter it became restricted to Antarctic waters and the convergence formed the northward limit of its range so far as the surface 250 m. is concerned (pp. 298–301).

5. The catches became progressively reduced in size during the winter months, and after midwinter in the South Pacific Ocean, the species had practically disappeared from the surface 250 m. (pp. 299–301).

6. Examination of the percentage of the total catch taken in the upper and lower nets in the summer in the Falkland Sector, and in April in the South Indian Ocean, strongly suggests that *R. gigas* undertakes seasonal vertical migrations similar to those of the species investigated in the northern hemisphere. It spends the summer months within the surface 100 m., and at the end of the summer descends below this level. At the end of April it had sunk out of range of the 250–100 m. net. It reappears again in the surface 250 m. in the spring, and in November returns once more to the layer between 0 and 100 m. (pp. 301–4). This theory has been confirmed by the work of the 'Discovery II' on her third commission (1933–5). Thus, while *R. gigas* spends the summer in northward-flowing Antarctic surface water, it spends the winter months in the southward-flowing warm deep water.

7. The species has two spawning periods during the year. One takes place in the summer in Antarctic surface water from mid-December onwards (in the Falkland Sector)—although the exact range of time covered by the spawning has not been fixed (pp. 323–30). The summer generation produced by this spawning descends into the warm deep water and spawns there probably in late May and the first half of June (pp. 338–40). This spawning produces the over-wintering generation which reappears in October in the surface 250 m. mainly in stages iv and v (pp. 323–6, 341).

8. It seems that the over-wintering generation spends the months July, August and September in warm deep water mostly in stages iv and v, but the stage reached by the spring seems to depend on the temperature of the water in which development occurs, since in the spring the winter generation reappears in sub-Antarctic water largely in the adult condition and in stage v. In Antarctic water, however, it reappears largely as stages iv and v, and in the coldest water, in the spring of 1931–2, comparatively large numbers of stage iii were found (p. 324). The over-wintered generation which reappeared at the surface in the western Drake Passage in the warmer spring of 1932–3 was in a more advanced condition than that which reappeared in the colder spring of 1931–2 (p. 341).

9. The over-wintered generation comes to maturity in late November and December around South Georgia (pp. 326, 343), and the approach of the spawning period is heralded by the appearance of ripe eggs in the ovaries of the adult females (pp. 316–19) and by an increase in the proportion of adult males in the lower nets (pp. 320–2).

10. In the Falkland Sector the summer spawning takes place in water of Bellingshausen Sea origin in the South Atlantic, western Scotia Sea and Drake Passage, within an optimum temperature range not exactly fixed but probably between 1·0 and 4·0° C. In the season 1931–2 it began in December in waters east of South Georgia and spread later into the Scotia Sea and Drake Passage. In the season 1932–3 spawning probably began earlier than in 1931–2 (pp. 326–30, 345).

11. No spawning at all took place, in 1931–2, in Weddell Sea water before the end of

January at least. One station taken in this water in March 1933 might perhaps suggest that a spawning may take place later in the season in warmer Weddell Sea water (pp. 330–2, 349).

12. The *Rhincalanus* population of the Weddell Sea is probably an invasion from an outside area and is carried into the Weddell Sea by warm deep water from the South Atlantic or by the deep current from the South Indian Ocean which flows westwards along the coast of Coats Land south of 66° S. (pp. 330–2, 349–51).

13. If no spawning at all takes place in the Weddell Sea the adult population found there in the summer must result from the winter spawning in the South Atlantic, and thus be six months old, or from the previous summer's spawning, and thus be a year old (p. 332).

14. In view of the different ages of the stock of *Rhincalanus* at different places at the same time of year, it is suggested that spawning takes place in colder Antarctic water later than in warmer water. There is thus a southward movement of the region of spawning from northern warmer water to more southerly colder water as the season advances. At temperatures below the optimum range for the spawning of the species the spawning is delayed. This delay, it is suggested, is the result of retardation of development by reduced temperatures. The parent generation in colder water takes longer to attain maturity and fails to spawn until either the temperature of the water has been raised to within the spawning range by the seasonal southward movement of the isotherms or the population has drifted into water of a suitable temperature for spawning (pp. 354–7).

15. It is further suggested that temperatures below a certain limit—tentatively placed between 0 and $-1{\cdot}0°$ C.—inhibit spawning altogether (p. 355).

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Table I *a*. *Hauls of the* 1-*m. net from which the Copepoda were examined*

Falkland Sector, 1931–2

St.	Date	Position: Lat.	Position: Long.	Upper net: Depth m.	Upper net: Time	Lower net: Depth m.	Lower net: Time	Average temp. 0–100 m. °C.	Remarks
	1931	Falkland Islands to Magellan Straits, Nov. 1931							
719	13. xi	54° 00·0′ S	60° 00·0′ W	109–0*	0641–0701	—	—	4·85	
721	13. xi	53° 58·5′ S	68° 59·1′ W	125–0*	1700–1720	250–144*	1700–1722	4·58	
722	14. xi	53° 55·8′ S	64° 14·0′ W	90–0*	0244–0302	—	—	5·40	
723	14. xi	53° 56·5′ S	66° 05·0′ W	79–0*	1100–1112	—	—	6·24	
		Western Drake Passage, Nov. 1931							
725	17. xi	53° 23·6′ S	74° 57·8′ W	150–0*	2146–2205	250–196*	2146–2220	6·24	
726	18. xi	55° 05·4′ S	75° 00·1′ W	108–0*	1213–1233	270–190*	1213–1246	5·92	
727	18. xi	56° 13·4′ S	75° 07·3′ W	124–0*	2250–2311	310–170*	2250–2313	5·30	
729	19. xi	58° 26·7′ S	75° 07·2′ W	102–0*	2306–2325	256–194*	2306–2337	4·54	← Antarctic convergence
731	20. xi	60° 35·8′ S	75° 03·7′ W	62–0*	2318–2338	246–170*	2318–2349	1·73	
733	21. xi	62° 56·7′ S	75° 02·0′ W	84–0*	2235–2255	300–140*	2334–0005	1·35	
		Ice edge (Southern Drake Passage), Nov. 1931							
735	22. xi	63° 55·0′ S	73° 28·8′ W	62–0*	2150–2220	216–168*	2150–2223	−1·59	
737	23. xi	62° 47·5′ S	69° 24·8′ W	109–0*	2301–2321	248–154*	2214–2345	−1·56	½ mile from pack-ice
739	24. xi	61° 25·9′ S	64° 32·0′ W	121–0*	2219–2239	172–85*	2133–2203	−1·47	
741	25. xi	59° 53·7′ S	61° 03·2′ W	123–0*	2226–2246	286–126*	2143–2212	−0·88	
		Eastern Drake Passage and South Atlantic, Nov. 1931							
743	26. xi	59° 23·0′ S	55° 54·1′ W	149–0*	2231–2311	264–108*	2148–2219	−0·56	
745	28. xi	57° 35·1′ S	55° 47·1′ W	117–0*	1138–1158	260–104*	1054–1125	−0·44	← Antarctic convergence
746	28. xi	56° 21·5′ S	55° 50·5′ W	125–0*	0121–0141	306–124*	0034–0104	2·59	
748	29. xi	55° 29·4′ S	54° 13·8′ W	180–0*	2315–2335	204–138*	2231–2300	3·99	
750	30. xi	54° 07·9′ S	54° 03·5′ W	166–0*	1334–1354	250–160*	1253–1322	4·47	
		Western Scotia Sea and South Atlantic, Dec. 1931							
751	1. xii	51° 28·7′ S	49° 17·7′ W	104–0*	2124–2145	269–138*	2124–2158	2·15	
753	2. xii	52° 02·4′ S	49° 12·5′ W	165–0*	2346–0007	280–110*	2258–2328	2·45	← Antarctic convergence
755	3. xii	55° 57·9′ S	48° 59·0′ W	130–0*	2226–2246	210–130*	2142–2212	0·36	
757	4. xii	58° 03·5′ S	48° 50·5′ W	156–0*	2324–2344	320–126*	0000–0030	−0·06	
759	5. xii	59° 06·5′ S	48° 39·9′ W	119–0*	0037–0057	260–100*†	2352–0022	0·09	
760	6. xii	60° 21·6′ S	48° 40·2′ W	176–0*	2339–2359	260–140*	2255–2325	−1·28	
		Eastern Scotia Sea, Dec. 1931							
761	7. xii	59° 46·3′ S	45° 30·5′ W	151–0*	0027–0047	290–140*	2341–0011	−0·88	
763	8. xii	59° 35·5′ S	42° 40·1′ W	124–0*	2314–2335	280–130*	2230–2300	−1·34	
765	9. xii	58° 11·3′ S	41° 16·3′ W	104–0*	2049–2109	206–114*	2007–2036	—	
766	10. xii	58° 51·0′ S	36° 54·0′ W	102–0*	2055–2115	230–110*	2011–2041	−1·53	
767	11. xii	57° 02·6′ S	36° 47·2′ W	—	—	270–118*	1120–1222	−0·12	Near drift ice and bergs
768	11. xii	56° 20·6′ S	36° 34·7′ W	119–0*	2220–2240	248–120*	2135–2206	0·38	Abundant diatoms in surface haul
769	12. xii	55° 15·4′ S	36° 16·4′ W	144–0*	0814–0834	342–150*	0729–0800	0·41	

* *Rhincalanus gigas* present.

† Closing depth of lower haul estimated.

Table I *a* (*cont.*)

St.	Date	Position		Upper net		Lower net		Average temp. 0–100 m. °C.	Remarks
		Lat.	Long.	Depth m.	Time	Depth m.	Time		
	1931	South Georgia area, Dec. 1931							
774	16. xii	52° 43·4′ S	37° 17·5′ W	137–0*	0812–0832	250–100*†	0727–0757	0·81	
775	16. xii	50° 48·3′ S	37° 21·6′ W	106–0*	2225–2245	288–112*	2143–2213	—	← Antarctic convergence
776	17. xii	49° 29·0′ S	37° 22·5′ W	120–0*	1411–1431	356–170*	1326–1355	4·21	
778	18. xii	52° 05·7′ S	35° 22·7′ W	119–0*	2344–0004	252–102*	2259–2329	1·70	Very abundant diatoms in surface haul
779	19. xii	53° 27·3′ S	34° 31·8′ W	146–0*	1244–1304	280–140*	1202–1232	0·57	
780	19. xii	54° 23·0′ S	33° 54·5′ W	114–0*	2317–2337	202–133*	2233–2303	−0·12	Very abundant diatoms in surface haul
788	21. xii	54° 00·2′ S	40° 24·7′ W	119–0*	1834–1854	280–100*	1754–1824	0·91	
		South Atlantic, Jan. 1932							
795	6. i	53° 44·6′ S	31° 02·1′ W	124–0*	2314–2334	310–124*	2230–2300	−0·22	
796	7. i	53° 47·1′ S	28° 14·9′ W	131–0*	1240–1300	248–102*	1200–1230	1·42	Some diatoms in surface haul
797	7. i	54° 44·7′ S	27° 20·8′ W	153–0*	2101–2121	250–122*	2016–2046	0·25	
798	8. i	54° 50·5′ S	25° 56·0′ W	100–0	1027–1038	242–116*	0918–0948	0·61	
799	8. i	54° 43·7′ S	24° 30·0′ W	131–0*	2351–0011	334–130*	2309–2339	0·91	
801	9. i	54° 26·4′ S	21° 11·1′ W	104–0*	1938–1958	210–128*	1857–1927	0·88	
802	10. i	54° 15·0′ S	19° 11·1′ W	126–0*	0721–0741	320–70*	0633–0704	1·97	
803	10. i	53° 24·7′ S	22° 19·1′ W	120–0*	2211–2231	308–130*	2130–2200	2·70	
		Weddell Sea, Jan. 1932							
804	11. i	55° 30·3′ S	21° 02·6′ W	130–0*	2348–0008	290–104*	2300–2330	−0·03	Abundant diatoms in surface haul
806	12. i	57° 27·2′ S	21° 28·8′ W	116–0*	2254–2314	216–104*	2254–2314	0·02	
807	13. i	58° 47·7′ S	21° 40·4′ W	137–0*	1150–1210	262–84*	1109–1139	−0·85	
808	13. i	59° 56·0′ S	22° 20·7′ W	120–0*	2316–2336	250–100*	2236–2306	0·11	
809	14. i	61° 09·9′ S	22° 36·9′ W	128–0*	1306–1326	196–104*	1221–1251	−1·6	Fairly abundant diatoms in surface haul
810	14. i	61° 30·7′ S	23° 12·3′ W	166–0*	2001–2121	304–130*	2019–2049	—	Among light ice
811	15. i	62° 44·0′ S	23° 18·4′ W	113–0*	1939–1959	—	—	−1·73	
812	16. i	64° 12·5′ S	22° 57·0′ W	137–0*	1252–1312	318–102*	1212–1242	−1·55	
813	16. i	64° 55·9′ S	23° 13·0′ W	135–0*	2301–2321	340–100*†	2215–2245	−1·60	
815	17. i	66° 57·3′ S	22° 38·3′ W	140–0*	2350–0010	314–188*	2310–0010	−1·53	
816	18. i	68° 09·6′ S	22° 01·7′ W	133–0*	1422–1442	256–80*	1340–1410	−1·35	
817	19. i	69° 59·6′ S	23° 53·0′ W	132–0*	0856–0916	260–126	0808–0838	−1·34	At edge of heavy pack-ice
		Weddell Sea, Eastern Scotia Sea, Jan. 1932							
818	20. i	68° 11·3′ S	24° 52·8′ W	77–0	1126–1146	—	—	—	Among pack-ice
819	20. i	67° 23·9′ S	25° 40·7′ W	105–0*	2027–2047	—	—	—	
820	21. i	65° 44·9′ S	28° 29·9′ W	110–0*	2243–2303	—	—	—	
822	23. i	63° 53·7′ S	33° 28·1′ W	146–0*	2056–2116	244–130*	2016–2046	—	
823	27. i	61° 24·4′ S	36° 03·6′ W	179–0*	1014–1034	312–119*	0928–1001	−1·3	At edge of pack-ice
824	27. i	59° 57·4′ S	36° 06·6′ W	157–0*	2111–2131	300–104*	2029–2059	—	Abundant diatoms in surface haul
825	28. i	56° 31·2′ S	36° 00·5′ W	117–0*	2015–2035	310–100*	2051–2121	—	
		Falkland Islands to South Georgia, Feb. 1932							
828	17. ii	51° 44·3′ S	55° 57·0′ W	141–0*	2228–2248	250–100*†	2146–2216	7·10	
829	18. ii	51° 42·8′ S	50° 31·7′ W	140–0*	2205–2225	270–84*	2121–2152	5·42	← Antarctic convergence
830	19. ii	52° 31·3′ S	44° 51·3′ W	117–0*	2307–2327	356–140*	2300–0011	4·15	
831	20. ii	53° 19·3′ S	39° 32·1′ W	130–0*	2341–2401	250–100*†	2300–2330	2·74	

* *Rhincalanus gigas* present. † Closing depth of lower haul estimated.

Table I *b*. *Hauls of the* 1-*m. net from which the Copepoda were examined Falkland Sector*, 1932–3

St.	Date	Position Lat.	Position Long.	Upper net Depth m.	Upper net Time	Lower net Depth m.	Lower net Time	Average temp. 0–100 m. °C.	Remarks
	1932			Falkland Islands to Magellan Straits, Oct. 1932					
979	15. x	51° 00·0′ S	62° 36·3′ W	117–0*	1109–1129	—	—	5·41	
980	15. x	51° 00·6′ S	64° 44·1′ W	104–0	2206–2223	—	—	4·96	
981	16. x	51° 01·1′ S	66° 58·2′ W	80–0	0916–0936	—	—	5·80	
				Western Drake Passage, Oct. 1932					
983	24. x	55° 10·0′ S	76° 04·7′ W	121–0*	2250–2310	300– 80*	2250–2320	5·83	
984	24. x	55° 14·4′ S	77° 48·6′ W	99–0*	1105–1125	240–100*	1105–1135	5·06	
985	24. x	55° 22·2′ S	79° 24·5′ W	113–0*	2209–2229	290–110*	2209–2239	4·96	
986	25. x	56° 28·9′ S	79° 28·2′ W	102–0*	1100–1120	244–114*	1100–1130	4·91	
988	26. x	59° 19·0′ S	79° 39·8′ W	88–0*	2240–2300	224– 74*	2240–2310	3·86	
990	27. x	61° 56·3′ S	79° 57·0′ W	96–0*	2229–2249	270–100*†	2229–2259	3·08	← Antarctic convergence
992	28. x	64° 19·2′ S	80° 06·0′ W	100–0*	2159–2219	270–110*	2159–2229	−1·54	
994	29. x	66° 45·7′ S	80° 19·8′ W	113–0*	2159–2219	270– 90*	2159–2229	−1·70	
995	30. x	67° 06·2′ S	79° 55·8′ W	125–0*‡	0342–0402	320–120*	0342–0412	—	In light pack-ice
				Ice edge (Southern Drake Passage) and Bransfield Straits, Oct.–Nov. 1932					
996	30. x	66° 53·8′ S	78° 52·6′ W	100–0	1646–1706	350– 90*	1646–1716	—	
				0–5*§	1645–1720				
997	30. x	66° 37·4′ S	78° 23·6′ W	0–5§	2025–2055	—	—	—	
				0–10§	2025–2055				
999	31. x	66° 55·8′ S	73° 51·5′ W	151–0*	2207–2227	—	—	—	
				0–5	2207–2237				
1000	1. xi	65° 06·6′ S	71° 39·7′ W	128–0*	1108–1128	300–110*	1108–1138	−1·63	
1001	1. xi	64° 53·8′ S	68° 43·9′ W	95–0*	2143–2203	230– 66*	2143–2213	−1·89	
1003	2. xi	63° 40·7′ S	63° 03·7′ W	115–0*	2050–2110	—	—	−1·28	
1004	5. xi	63° 02·2′ S	60° 25·5′ W	123–0	1259–1319	320–120*	1259–1329	−0·73	
1005	5. xi	63° 09·0′ S	60° 11·0′ W	109–0	1615–1635	300–100*	1615–1645	−1·19	
1006	5. xi	63° 16·7′ S	60° 06·5′ W	115–0	1940–2000	320–152	1940–2010	−0·93	
1009	6. xi	62° 55·9′ S	58° 00·3′ W	155–0*	0545–0605	300–120†	0545–0615	—	
				Eastern Drake Passage and South Atlantic, Nov. 1932					
1011	6. xi	62° 40·4′ S	56° 19·5′ W	100–0*	1214–1234	—	—	−1·48	
1013	6. xi	61° 57·5′ S	56° 20·1′ W	93–0	2210–2230	314–140*	2210–2240	−1·11	
1014	7. xi	61° 26·8′ S	56° 19·7′ W	144–0	0320–0340	—	—	−1·01	
1015	7. xi	58° 53·2′ S	56° 18·6′ W	128–0*	2210–2230	350–120*	2210–2240	−0·49	
1017	8. xi	56° 00·2′ S	56° 07·6′ W	110–0*	2216–2236	350–150*	2216–2246	0·43	← Antarctic convergence
1019	9. xi	53° 22·6′ S	56° 02·0′ W	119–0*	2143–2203	320–110*	2143–2213	4·96	
				South Atlantic, Nov. 1932					
1021	13. xi	51° 20·1′ S	55° 20·1′ W	120–0*	2119–2139	315–150*	2119–2149	5·23	
1023	16. xi	50° 48·9′ S	51° 32·9′ W	112–0*	2152–2213	318–130*	2152–2223	4·93	
1025	17. xi	50° 18·3′ S	47° 12·4′ W	140–0*	2137–2157	400–160*	2137–2207	3·72	← Antarctic convergence
				Western Scotia Sea and South Atlantic, Nov. 1932					
1027	18. xi	51° 19·8′ S	44° 40·8′ W	100–0*	2139–2159	300–125*	2139–2209	2·54	
1029	19. xi	54° 20·7′ S	44° 35·8′ W	100–0*	2158–2218	300–150*	2158–2228	0·92	
1031	20. xi	56° 56·4′ S	44° 32·3′ W	149–0*	2153–2213	370–104*	2153–2223	0·52	
1033	21. xi	59° 38·2′ S	44° 30·8′ W	113–0*	2318–2338	270–100*	2318–2348	−0·10	
1034	24. xi	60° 57·6′ S	44° 39·8′ W	165–0*	1220–1240	—	—	−1·26	
1035	24. xi	61° 56·2′ S	44° 44·2′ W	100–0*	2219–2239	274–116*	2219–2249	−1·26	Among drift-ice
				0–5§	2220–2250				

* *Rhincalanus gigas* present.
‡ Net failed to fish properly.
† Closing depth of lower net estimated.
§ Net towed horizontally.

Table I *b* (*cont.*)

St.	Date	Position Lat.	Position Long.	Upper net Depth m.	Upper net Time	Lower net Depth m.	Lower net Time	Average temp. 0–100 m. °C.	Remarks
	1932	Scotia Sea and South Atlantic (east of South Georgia), Nov.–Dec. 1932							
1038	25. xi	61° 39·4′ S	40° 00·3′ W	151–0*	2227–2247	375–110*	2227–2247	−1·24	
1041	26. xi	60° 31·3′ S	36° 19·5′ W	84–0*	2110–2130	250–100*	2110–2140	−1·27	Near pack-ice
1044	27. xi	60° 00·6′ S	32° 21·6′ W	117–0*	2108–2128	296–100*	2108–2138	−1·41	Near pack-ice
1045	29. xi	58° 33·0′ S	27° 04·9′ W	100–0*	1036–1056	256–110*	1036–1106	−1·64	Near pack-ice
1047	30. xi	58° 26·9′ S	26° 09·3′ W	84–0*	0438–0458	230– 86*	0438–0510	−1·35	
1048	30. xi	56° 32·2′ S	27° 21·9′ W	119–0*	1547–1607	340–110*	1547–1617	−0·81	
1050	1. xii	53° 46·6′ S	31° 09·2′ W	103–0*	2212–2232	295–104*	2212–2242	−0·54	
1052	2. xii	52° 10·1′ S	33° 22·2′ W	133–0*	2104–2124	338–130*	2104–2134	0·86	
1054	3. xii	50° 07·8′ S	35° 48·6′ W	98–0*	2226–2246	250– 90*	2226–2256	2·48	
1056	4. xii	50° 18·0′ S	37° 04·5′ W	100–0*	2139–2159	340–150*	2139–2209	3·33	Diatoms fairly abundant in surface haul
		South Georgia, Dec. 1932							
1063	11. xii	52° 04·7′ S	38° 08·8′ W	128–0*	1231–1251	334–114*	1231–1301	—	
1066	12. xii	53° 53·6′ S	40° 30·5′ W	94–0*	0228–0248	276–105*	0228–0258	—	
1073	13. xii	54° 59·6′ S	36° 38·9′ W	117–0*	0628–0648	—	—	—	Diatoms fairly abundant
1076	13. xii	54° 24·0′ S	34° 07·1′ W	110–0*	2134–2154	270–100*	2134–2204	0·66	,, ,,
		Scotia Sea, Dec. 1932–Jan. 1933							
1083	30. xii	54° 37·5′ S	40° 35·9′ W	125–0*	0919–0939	250–100*	0919–0949	—	
1085	31. xii	57° 00·0′ S	41° 53·9′ W	146–0*	0918–0938	250–125*	0918–0948	—	
	1933								
1088	1. i	60° 12·1′ S	44° 29·9′ W	100–0*	2149–2209	260–120*	2149–2219	−0·4	
		Bransfield Straits, Jan.–Feb. 1933							
1097	31. i	61° 40·1′ S	50° 27·0′ W	119–0*	0931–0951	280–124*	0931–1001	—	At edge of loose pack-ice
1101	1. ii	61° 50·8′ S	54° 42·9′ W	153–0	2301–2321	250–100*	2301–2331	−0·40	
1108	4. ii	62° 22·3′ S	58° 30·5′ W	134–0	1321–1341	290–100*	1321–1351	0·02	
1110	4. ii	62° 57·5′ S	57° 38·6′ W	135–0*	2133–2153	—	—	−0·84	
		Drake Passage, Feb. 1933							
1115	6. ii	60° 39·2′ S	61° 31·9′ W	119–0	2215–2235	315–130*	2215–2245	0·58	
1116	7. ii	59° 17·2′ S	61° 04·4′ W	110–0*	0926–0946	270–115*	0926–0956	—	
1117	7. ii	57° 46·1′ S	60° 30·9′ W	100–0*	2245–2305	320–120*	2245–2305	4·11	← Antarctic convergence
1119	8. ii	55° 07·9′ S	59° 18·5′ W	100–0*	2247–2307	330–100*	2247–2317	6·09	
		South Atlantic, Feb. 1933							
1122	20. ii	52° 04·6′ S	50° 54·5′ W	70–0*	0928–0948	190–115*	0928–0958	—	
1123	20. ii	52° 12·6′ S	48° 25·3′ W	102–0*	2312–2332	250–100*	2312–2342	4·74	← Antarctic convergence
1125	21. ii	52° 21·5′ S	43° 34·5′ W	97–0*	2222–2242	290–100*	2222–2252	3·19	
1127	23. ii	52° 43·7′ S	37° 12·5′ W	100–0*	0604–0624	260– 90*	0604–0634	2·08	
1131	24. ii	54° 22·6′ S	34° 08·4′ W	100–0*	1619–1639	250–106*	1619–1649	1·22	
		Weddell Sea, March 1933							
1138	2. iii	55° 55·5′ S	31° 15·6′ W	132–0*	2237–2257	335–100*	2237–2307	0·76	
1140	3. iii	57° 21·1′ S	27° 09·9′ W	104–0*	2202–2222	310–110*	2202–2232	0·21	
1142	4. iii	58° 44·3′ S	22° 30·9′ W	93–0*	2315–2335	260–110*	2315–2345	1·02	
1144	5. iii	59° 44·5′ S	17° 30·8′ W	119–0*	2221–2241	340–100*	2221–2251	−0·37	
1146	6–7. iii	61° 00·2′ S	12° 03·8′ W	104–0*	2344–0004	290–110*	2344–0014	−0·58	
1148	9. iii	63° 52·0′ S	0° 54·9′ W	117–0*	2324–2344	330–100*	2324–2354	−0·74	
1150	10. iii	65° 21·6′ S	4° 33·7′ E	91–0*	2219–2239	270–100*	2219–2249	−0·08	
1152	11. iii	68° 03·0′ S	8° 03·0′ E	115–0*	2304–2324	—	—	—	
1153	12. iii	69° 22·0′ S	9° 37·5′ E	117–0*	0925–0945	365–110*	0925–0945	—	Among streams of pack-ice
		South Atlantic, March 1933							
1161	19. iii	50° 23·1′ S	13° 55·2′ E	90–0*	1621–1641	340–150*	1621–1651	—	

* *Rhincalanus gigas* present.

Table I *c*. *Hauls of the* 1-*m. net from which the Copepoda were examined*
Circumpolar cruise, February to October 1932

St.	Date	Position		Upper net		Lower net		Average temp. 0–100 m. °C.	Remarks
		Lat.	Long.	Depth m.	Time	Depth m.	Time		
	1932	South Georgia to Cape Town, Feb.–Mar. 1932							
833	22. ii	53° 58·3′ S	35° 50·0′ W	173–0*	2232–2252	—	—	—	
834	23. ii	52° 17·1′ S	31° 01·0′ W	146–0*	2118–2138	250–100*†	2031–2102	—	← Antarctic
835	25. ii	49° 13·5′ S	22° 29·2′ W	115–0	1017–1037	—	—	—	convergence
836	27. ii	45° 28·0′ S	11° 40·4′ W	102–0*	0924–0944	250–100*†	0959–1028	—	
837	27. ii	44° 44·0′ S	09° 38·0′ W	125–0	2025–2055	250–100†	2025–2055	—	
838	28. ii	42° 56·0′ S	04° 52·2′ W	137–0	2058–2118	250–100*†	2016–2046	—	
839	29. ii	41° 04·4′ S	00° 14·3′ W	132–0	2104–2124	250–100†	2019–2049	—	
840	1. iii	39° 21·0′ S	04° 20·5′ E	101–0	2059–2119	250–100†	2017–2047	—	
841	2. iii	37° 46·0′ S	08° 39·3′ E	130–0	2053–2113	320–140	2013–2043	—	
842	3. iii	36° 04·8′ S	13° 34·5′ E	155–0	2050–2110	—	—	—	
				280–0	2009–2049				
		Cape Town to Enderby Land, April 1932							
844	8. iv	35° 10·3′ S	19° 06·1′ E	155–0	2057–2117	—	—	17·13	
845	9. iv	38° 08·0′ S	20° 56·1′ E	—	—	242–180	2328–0000	16·43	
846	10. iv	40° 41·3′ S	23° 02·0′ E	128–0	0230–0250	370–170	0146–0216	14·52	← Antarctic
847	11. iv	43° 07·4′ S	25° 04·6′ E	119–0	0059–0119	270–196	0015–0046	14·51	convergence
848	12. iv	45° 48·4′ S	27° 13·6′ E	117–0	0037–0057	270–166*	2355–0025	6·86	
849	14. iv	48° 14·6′ S	29° 23·7′ E	71–0	0529–0549	210–125*	0530–0600	7·90	
850	15. iv	50° 43·8′ S	31° 44·0′ E	100–0*	0528–0548	254–140*	0528–0558	1·70	
851	17. iv	56° 22·1′ S	37° 22·3′ E	125–0*	0411–0431	320–190*	0411–0431	1·10	
852	18. iv	58° 39·5′ S	40° 03·9′ E	119–0*	0429–0449	370–155*	0345–0415	0·24	
853	19. iv	61° 00·2′ S	43° 11·1′ E	119–0*	0435–0455	190–108*	0355–0425	−0·33	
854	20. iv	63° 30·2′ S	46° 24·9′ E	119–0*	0342–0402	248– 94*	0255–0330	−0·16	
855	20. iv	65° 15·0′ S	48° 43·7′ E	125–0*	2310–2330	280–154*	2310–2340	−1·64	Among streams of drift-ice
		Enderby Land to Fremantle, April–May 1932							
856	22. iv	61° 06·6′ S	53° 39·8′ E	89–0*	2230–2250	224–120*	2230–2310	0·07	
857	23. iv	60° 40·1′ S	59° 23·7′ E	130–0*	0212–0232	262–140*	0132–0202	−0·33	
858	24. iv	60° 10·1′ S	63° 54·8′ E	88–0*	2336–0006	264–130*	2336–0006	0·33	
859	25. iv	59° 19·1′ S	68° 51·8′ E	100–0*	2351–0011	210–140*	2351–0023	0·60	
860	26. iv	57° 56·4′ S	73° 58·8′ E	119–0*	2349–0009	300–100*	2349–0020	0·46	
861	27. iv	56° 28·9′ S	79° 18·2′ E	109–0*	0019–0039	254–110*	0019–0049	0·66	
862	28. iv	55° 33·8′ S	83° 00·4′ E	102–0*	2313–2333	220– 98*	2313–2343	1·75	
863	29. iv	54° 15·3′ S	88° 22·4′ E	90–0*	0127–0147	200– 82*	0127–0159	1·65	
865	1. v	52° 48·4′ S	94° 56·0′ E	116–0*	0620–0640	290–150*‡	0711–0741	—	
866	1. v	51° 22·6′ S	96° 26·4′ E	98–0	0334–0354	284–110*	0334–0404	3·58	← Antarctic
867	2. v	49° 25·5′ S	98° 21·8′ E	139–0	2313–2333	330–150*	2313–2343	5·35	convergence
868	3. v	46° 55·0′ S	100° 45·6′ E	98–0	2237–2257	240–100	2237–2308	6·25	
869	4. v	43° 56·5′ S	103° 24·3′ E	68–0§	0030–0050	240–120	0030–0100	10·64	
870	5. v	41° 41·7′ S	105° 16·0′ E	95–0	0051–0111	250– 90	0051–0123	10·64	
871	6. v	39° 32·1′ S	107° 06·4′ E	91–0	0152–0212	240–100	0152–0222	12·56	
872	7. v	37° 09·1′ S	108° 47·2′ E	128–0	2258–2318	300–146	2258–2328	15·59	
873	8. v	34° 19·1′ S	110° 21·7′ E	—	—	220–110	2218–2248	18·96	

* *Rhincalanus gigas* present.
† Depths estimated.
‡ Closing depth of lower net estimated.
§ Net fished for some time near surface.

Table I *c* (*cont.*)

St.	Date	Position Lat.	Position Long.	Upper net Depth m.	Upper net Time	Lower net Depth m.	Lower net Time	Average temp. 0–100 m. °C.	Remarks
	1932			Fremantle to ice edge, May 1932					
877	17. v	35° 12·5′ S	114° 42·5′ E	102–0	0001–0022	250–100	0001–0031	19·49	
878	18. v	38° 01·0′ S	115° 38·6′ E	125–0	2343–0003	294– 80	2343–0013	18·55	
879	19. v	40 56·7′ S	116° 46·5′ E	86–0	2353–0013	200– 94	2353–0026	12·00	
880	20. v	43 53·1′ S	117° 50·8′ E	110–0	0002–0022	265– 90	0002–0032	9·74	
881	21. v	47 00·0′ S	119° 00·3′ E	119–0	2231–2251	260–100	2231–2301	8·24	← Antarctic
882	22. v	49 52·9′ S	120° 28·6′ E	102–0	2318–2338	210– 80	2318–2349	5·05	convergence
883	23. v	52 54·0′ S	122° 03·8′ E	89–0*	2230–2250	210– 90*	2230–2302	3·73	
884	24. v	56° 08·3′ S	124° 04·8′ E	122–0*	0016–0036	270– 90*	0016–0046	1·91	
885	25. v	58° 50·6′ S	125° 54·9′ E	116–0*	2334–2354	280–120*	2334–0004	1·01	
886	26. v	61° 12·1′ S	127° 52·9′ E	133–0*	2353–0013	302–100*	2353–0023	−0·41	
887	27. v	63° 41·4′ S	130° 07·0′ E	86–0*	2119–2139	235–115*	2119–2149	—	In streams of very light pack-ice
				120–0*	2202–2222				
				Ice edge to Melbourne, May–June, 1932					
889	28. v	61° 44·6′ S	131° 38·4′ E	106–0*	0037–0057	290– 90*	0037–0107	0·20	
890	29. v	59° 04·5′ S	133° 18·5′ E	98–0*	2312–2332	240–110*	2312–2341	0·68	
891	30. v	56° 02·9′ S	135° 10·5′ E	121–0*	2322–2342	260– 90*	2322–2352	3·08	← Antarctic
892	31. v	52° 48·5′ S	137° 00·4′ E	93–0	2245–2305	220–100	2245–2320	5·20	convergence
893	1. vi	49° 37·5′ S	138° 35·3′ E	100–0	2336–2356	260–100	2336–0006	7·54	
894	2. vi	46° 31·5′ S	139° 50·0′ E	91–0	2307–2327	235–105	2307–2345	9·67	
895	3. vi	43° 15·5′ S	143° 38·4′ E	80–0	2329–2349	250–110	0022–0052	11·13	
				Melbourne to ice edge, June 1932					
897	14. vi	41° 05·9′ S	148° 56·0′ E	117–0	0107–0127	315–120	0107–0137	13·53	
898	15. vi	43° 55·5′ S	149° 32·2′ E	128–0	2226–2246	310–120	2226–2256	13·29	
899	16. vi	47° 18·2′ S	150° 20·8′ E	117–0	0000–0020	—	—	10·57	
				330–0	0000–0030	—	—	—	
900	17. vi	49° 26·7′ S	150 57·6′ E	135–0	2227–2247	340–140	2227–2257	6·92	
902	19. vi	51° 23·9′ S	151° 11·4′ E	120–0	0940–1000	330–150	0940–1010	—	
903	19. vi	53° 32·0′ S	151° 33·4′ E	131–0	0037–0057	370–140*	0037–0057	4·91	← Antarctic
904	20. vi	56° 13·1′ S	152° 15·8′ E	104–0	2222–2242	330–130*	2222–2252	1·96	convergence
905	21. vi	59° 11·6′ S	153° 11·4′ E	114–0*	2323–2343	320–138*	2323–2353	−0·50	
906	22. vi	61 24·7′ S	154 26·2′ E	100–0*	2324–2344	386–142*	2324–2354	−1·38	
907	23. vi	61° 21·5′ S	153° 59·3′ E	—	—	290–110*†	0959–1029	—	In soft new ice
				Ice edge to New Zealand, June–July 1932					
911	23. vi	61° 18·2′ S	155° 37·1′ E	106–0*	2026–2046	300–110*	2026–2057	−0·98 ‖	
919	25. vi	57° 50·4′ S	160° 23·1′ E	128–0*	2250–2310	306–130*	2250–2320	1·69	← Antarctic
920	26. vi	54° 41·1′ S	162° 23·1′ E	123–0	2316–2336	320–100*	2316–2346	2·93	convergence
921	27. vi	51° 39·4′ S	163° 52·2′ E	114–0†	2145–2205	250–100	2145–2206	7·74	
922	28. vi	50° 19·6′ S	163° 49·4′ E	121–0	0727–0747	338–192	0727–0757	8·22	
923	29. vi	47° 11·7′ S	163° 41·4′ E	100–0	0618–0638	240–138	0618–0658	8·89	
924	30. vi	44 17·5′ S	165° 46·2′ E	95–0	0720–0740	220– 95	0720–0750	11·34	
925	1. vii	41° 20·5′ S	167° 55·5′ E	110–0	0743–0803	282–126	0743–0813	12·08	
926	2. vii	38° 01·9′ S	170° 12·8′ E	81–0	0744–0804	198–100	0744–0814	14·16	

* *Rhincalanus gigas* present. † Depths estimated.

‖ Calculated from observations at St. 912.

Table I c (cont.)

St.	Date	Position Lat.	Position Long.	Upper net Depth m.	Upper net Time	Lower net Depth m.	Lower net Time	Average temp. 0–100 m. °C.	Remarks
	1932		South Pacific Ocean, Aug.–Oct. 1932						
942	31. viii	42° 46·3′ S	176° 14·8′ E	132–0	2149–2209	350–110	2149–2219	9·13	
943	1. ix	45° 28·4′ S	179° 06·4′ E	128–0	2322–2342	356–130	2322–2352	7·39	
945	3. ix	48° 25·6′ S	177° 24·5′ W	102–0*	0947–1007	255– 80	0947–1018	—	
946	3. ix	49° 24·6′ S	176° 21·3′ W	128–0	2237–2257	270–120	2237–2307	6·81	
947	4. ix	51° 59·2′ S	173° 26·9′ W	117–0	2345–0005	310–130	2345–0015	6·93	
948	5. ix	54° 24·9′ S	170° 13·0′ W	115–0*	0008–0028	310–132*	0008–0038	4·71	
949	6. ix	56° 49·6′ S	166° 55·9′ W	117–0	2334–2354	320–120	2334–0004	3·12	← Antarctic convergence
950	7. ix	59° 05·3′ S	163° 46·5′ W	102–0	2330–2350	300–130	2330–0000	0·59	
951	8. ix	61° 26·3′ S	160° 02·9′ W	117–0	2219–2239	340–130	2219–2249	−1·60	
956	9. ix	62° 12·8′ S	158° 11·0′ W	97–0	1351–1411	280–100	1351–1421	−1·78	Near edge of light pack-ice
958	10. ix	61° 53·9′ S	155° 42·4′ W	100–0	1241–1301	260–114	1241–1315	—	Among scattered floes
959	10. ix	61° 07·0′ S	153° 57·2′ W	91–0	0012–0032	240–110	0012–0042	−1·70	
960	11. ix	58° 31·4′ S	150° 02·9′ W	137–0	0037–0057	290–134	0037–0107	−1·40	
961	12. ix	56° 16·4′ S	146° 22·3′ W	109–0 290–0*	2216–2236 2216–2246	325–144*	2307–2337	0·56	Hauls from 325–144 and 290–0 m. analysed together
962	13. ix	54° 02·8′ S	142° 25·4′ W	124–0	0027–0047	320–100*	0027–0057	5·03	← Antarctic convergence
963	14. ix	52° 01·1′ S	139° 13·2′ W	117–0*	2242–2302	320–128	2242–2312	6·47	
964	15. ix	49° 42·1′ S	135° 33·2′ W	110–0	2326–2346	250–100	2326–2356	6·83	
965	16. ix	47° 16·9′ S	132° 25·1′ W	121–0	2242–2302	310–132	2242–2312	7·08	
966	17. ix	44° 40·3′ S	129° 27·9′ W	102–0	2332–2352	250–100†	2332–0002	8·44	
967	19. ix	41° 03·1′ S	126° 03·9′ W	110–0	0743–0803	306–145	0743–0813	9·66	
968	19. ix	42° 30·0′ S	124° 51·7′ W	86–0	2016–2036	250–106	2016–2046	—	
969	20. ix	45° 36·1′ S	122° 09·5′ W	89–0	2247–2307	250–100†	2247–2317	7·80	
970	25. ix	55° 26·7′ S	115° 00·8′ W	141–0*	1210–1230	380–110*	1210–1240	3·70	
971	25. ix	56° 22·9′ S	113° 58·5′ W	117–0*	2018–2038	340–120	2018–2048	—	
972	26. ix	59° 21·8′ S	109° 59·5′ W	128–0*	2308–2328	300–122*	2308–2338	1·61	← Antarctic convergence
973	27. ix	61° 47·8′ S	105° 37·1′ W	100–0	2016–2036	270–120*	2016–2046	—	
974	28. ix	63° 57·0′ S	101° 16·0′ W	115–0	1717–1737	314–114	1717–1745	−0·89	
975	29. ix	61° 29·9′ S	94° 06·7′ W	117–0	2321–2341	290–104*	2321–2352	0·41	
976	30. ix	59° 22·0′ S	89° 03·9′ W	73–0*	2304–2324	190– 84*	2304–2334	2·60	
977	1. x	57° 18·2′ S	84° 29·5′ W	119–0*	2249–2309	318–140	2249–2319	4·61	
978	2. x	55° 18·4′ S	80° 08·1′ W	117–0*	2243–2303	298–108*	2243–2313	4·97	

* *Rhincalanus gigas* present. † Depth estimated.

Table II. *Approximate depth of discontinuity between Antarctic surface layer and warm deep water*

St.	Date	Upper net. Depth (m.)	Lower net. Depth (m.)	Approx. depth of discontinuity (m.)	St.	Date	Upper net. Depth (m.)	Lower net. Depth (m.)	Approx. depth of discontinuity (m.)
				(a) Falkland Sector 1931–2					
	1931					1931			
731	20. xi	62–0	246–170	250	780	19. xii	114–0	202–133	200
733	21. xi	84–0	300–140	300	788	21. xii	119–0	280–100	175*
735	22. xi	62–0	216–168	150**					
737	23. xi	109–0	248–154	200*		1932			
739	24. xi	121–0	172– 85	200	795	6. i	124–0	310–124	250*
741	25. xi	123–0	286–126	175*	796	7. i	131–0	248–102	125*
743	26. xi	149–0	264–108	125*	798	8. i	100–0	242–116	200*
745	28. xi	117–0	260–104	150*	799	8. i	131–0	334–130	175*
746	28. xi	125–0	306–124	400	802	10. i	126–0	320– 70	250*
755	3. xii	130–0	210–130	250	804	10. i	130–0	290–104	175*
757	4. xii	156–0	320–126	350	806	12. i	116–0	216–104	150*
759	5. xii	119–0	260–? 100	200*	807	13. i	137–0	262– 84	250*
760	6. xii	176–0	260–140	300	808	13. i	120–0	250–100	250
761	7. xii	151–0	290–140	350	809	14. i	128–0	196–104	250
766	10. xii	102–0	230–110	225*	812	16. i	137–0	318–102	175*
767	11. xii	—	270–118	250*	813	16. i	135–0	340–100	150*
768	11. xii	119–0	248–120	250	815	17. i	140–0	314–188	150**
769	12. xii	144–0	342–150	250*	816	18. i	133–0	256– 80	150*
774	16. xii	137–0	250–100	175*	817	19. i	132–0	260–126	150*
776	17. xii	120–0	356–170	300*	823	27. i	179–0	312–119	350
778	18. xii	119–0	352–102	175*	830	19. ii	117–0	356–140	350
779	19. xii	146–0	280–140	175*	831	20. ii	130–0	250–100	250
				(b) Falkland Sector 1932–3					
	1932					1932			
992	28. x	100–0	270–110	175*	1054	3. xii	98–0	250– 90	200*
994	29. x	113–0	270– 90	150*	1056	4. xii	100–0	340–150	300*
1001	1. xi	95–0	230– 66	100*	1076	13. xii	110–0	270–100	150*
1015	7. xi	128–0	350–120	150*					
1017	8. xi	110–0	350–150	150**		1933			
1025	17. xi	140–0	400–160	400	1088	1. i	100–0	260–120	300
1027	18. xi	100–0	300–125	400	1115	6. ii	119–0	315–130	100**
1029	19. xi	100–0	300–150	150**	1125	21. ii	97–0	290–100	250*
1031	20. xi	149–0	370–104	200*	1127	23. ii	100–0	260– 90	150*
1033	21. xi	113–0	270–100	100**	1131	24. ii	100–0	250–106	200*
1035	24. xi	100–0	274–116	80**	1138	2. iii	132–0	335–100	250*
1038	25. xi	151–0	375–110	300*	1140	3. iii	104–0	310–110	300*
1041	26. xi	84–0	250–100	175*	1142	4. iii	93–0	260–110	300
1044	27. xi	117–0	296–100	150*	1144	5. iii	119–0	340–110	175*
1045	29. xi	100–0	256–110	200*	1146	6. iii	104–0	290–110	175*
1048	30. xi	119–0	340–110	200*	1148	9. iii	117–0	330–100	150*
1050	1. xii	103–0	295–104	150*	1150	10. iii	91–0	270–100	80**
1052	2. xii	133–0	338–130	125					
				(c) Circumpolar Stations, April–September 1932					
	1932					1932			
850	15. iv	100–0	254–140	300	890	29. v	98–0	240–110	200*
851	17. iv	125–0	320–190	200*	891	30. v	121–0	260– 90	250*
852	18. iv	119–0	370–155	150**	904	20. vi	104–0	330–130	200*
853	19. iv	119–0	190–108	125*	905	21. vi	114–0	320–138	100**
854	20. iv	119–0	248– 94	100*	906	22. vi	100–0	386–142	100**
855	20. iv	125–0	280–154	125**	919	25. vi	128–0	306–130	125**
856	22. iv	89–0	224–120	125*	920	26. vi	123–0	320–100	300*
857	23. iv	130–0	262–140	125**	950	7. ix	102–0	300–130	225*
858	24. iv	88–0	264–130	175*	951	8. ix	117–0	340–130	125**
859	25. iv	100–0	210–140	175*	956	9. ix	97–0	280–100	150*
860	26. iv	119–0	300–100	175*	959	10. ix	91–0	240–110	150*
861	27. iv	109–0	254–110	175*	960	11. ix	137–0	290–134	150*
884	24. v	122–0	270– 90	200*	961	12. ix	109–0	325–144	250*
885	25. v	116–0	280–120	200*	972	26. ix	128–0	300–122	300
886	26. v	133–0	302–100	125*	974	28. ix	115–0	314–114	200*
887	27. v	86–0	235–115	70**	975	29. ix	117–0	290–104	300
889	28. v	106–0	290– 90	250*					

* Deep hauls fished partly in warm deep water. ** Deep hauls fished wholly in warm deep water.

Table III *a*. *Horizontal distribution of* Rhincalanus gigas
Falkland Sector, 1931–2

St.	Date	Upper net				Lower net				Total catch	% of *R. gigas* in total Copepoda	Position of Antarctic convergence
		Depth (m.)	Number examined	Fraction examined	Estimated total	Depth (m.)	Number examined	Fraction examined	Estimated total			
	1931	Falkland Islands to Magellan Straits, Nov. 1931										
719	13. xi	109–0	6	1/1	6	—	—	—	—	6	(24·0)	
721	13. xi	125–0	1	1/5	5	250–144	10	1/1	10	15	—	
722	14. xi	90–0	59	1/1	59	—	—	—	—	59	22·9	
723	14. xi	79–0	4	1/2	8	—	—	—	—	8	5·2	
		Western Drake Passage, Nov. 1931										
725	17. xi	150–0	104	1/8	832	250–196	149	1/10	1,490	2,322	19·4	
726	18. xi	108–0	82	1/8	656	270–190	110	1/1	110	766	23·05	
727	18. xi	124–0	202	1/10	2,020	310–170	136	1/2	272	2,292	25·3	
729	19. xi	102–0	135	1/4	540	256–194	717	1/4	2,868	3,408	49·05	←
731	20. xi	62–0	637	1/20	12,740	246–170	514	1/1	514	13,254	89·3	
733	21. xi	84–0	516	1/20	10,320	300–140	494	1/8	3,592	13,912	84·25	
		Ice edge (Southern Drake Passage), Nov. 1931										
735	22. xi	62–0	311	1/8	2,488	216–168	786	1/8	6,288	8,776	63·25	
737	23. xi	109–0	255	1/40	10,200	248–150	539	1/10	5,390	15,590	79·25	
739	24. xi	121–0	246	1/50	12,300	172– 85	647	1/50	32,350	44,650	83·4	
741	25. xi	123–0	140	1/5	700	286–126	322	1/5	1,610	2,310	61·0	
		Eastern Drake Passage and South Atlantic, Nov. 1931										
743	26. xi	149–0	367	1/1	367	264–108	290	1/5	1,450	1,817	73·6	
745	28. xi	117–0	200	1/50	10,000	260–104	415	1/8	3,320	13,320	89·1	←
746	29. xi	125–0	347	1/4	1,388	306–124	444	1/25	11,100	12,488	91·7	
748	29. xi	180–0	383	1/5	1,915	204–138	416	1/5	2,080	3,995	70·6	
750	30. xi	97–0	381	1/5	1,905	280–130	357	1/10	3,570	5,475	69·4	
		Western Scotia Sea and South Atlantic, Dec. 1931										
751	1. xii	104–0	773	1/10	7,730	269–138	397	1/5	1,985	9,715	71·1	
753	2. xii	165–0	192	1/1	192	280–110	795	1/2	1,590	1,782	59·9	←
755	3. xii	130–0	345	1/50	17,250	210–130	356	1/5	1,780	19,030	84·6	
757	4. xii	156–0	10	1/1	10	320–136	497	1/1	497	507	46·1	
759	5. xii	119–0	107	1/1	107	260–100	380	1/1	380	487	39·5	
760	6. xii	178–0	11	1/1	11	260–140	41	1/1	41	52	15·05	
		Eastern Scotia Sea, Dec. 1931										
761	8. xii	151–0	108	1/1	108	290–140	156	1/1	156	264	43·4	
763	8. xii	124–0	123	1/5	615	280–100	70	1/1	70	685	21·4	
765	9. xii	104–0	393	1/8	3,144	206–114	473	1/1	473	3,617	57·8	
766	10. xii	102–0	145	1/4	580	230–110	100	1/1	100	680	11·7	
767	11. xii	—	—	—	—	270–118	75	1/10	750	—	(25·6)	
768	11. xii	119–0	177	1/10	1,770	248–120	357	1/2	714	2,484	36·0	
769	12. xii	144–0	465	1/10	4,650	342–150	205	1/5	1,025	5,675	43·8	

Table III *a* (*cont.*)

St.	Date	Upper net Depth (m.)	Upper net Number examined	Upper net Fraction examined	Upper net Estimated total	Lower net Depth (m.)	Lower net Number examined	Lower net Fraction examined	Lower net Estimated total	Total catch	% of *R. gigas* in total Copepoda	Position of Antarctic convergence
	1931					South Georgia area, Dec. 1931						
774	16. xii	137–0	92	1/1	92	250–100	1015	1/1	1,015	1,107	83·6	
775	16. xii	106–0	367	1/50	18,350	288–112	128	1/5	640	18,990	50·0	
776	17. xii	120–0	414	1/5	2,070	256–170	651	1/5	3,255	5,325	86·5	←
778	18. xii	119–0	164	1/50	8,200	252–102	169	1/4	676	8,876	52·7	
779	19. xii	146–0	193	1/1	193	280–140	228	1/4	912	1,105	57·3	
780	19. xii	114–0	79	1/10	790	202–133	259	1/2	518	1,308	30·3	
788	21. xii	119–0	663	1/8	5,304	280–100	355	1/4	1,420	6,724	85·0	
						South Atlantic, Jan. 1932						
795	6. i	124–0	6	1/1	6	310–120	202	1/1	202	208	15·1	
796	7. i	131–0	960	1/1	960	248–102	489	1/4	1,956	2,916	74·9	
797	7. i	153–0	10	1/1	10	250–122	206	1/1	206	216	60·3	
798	8. i	100–0	0	—	—	242–116	213	1/1	213	213	—	
799	8. i	164–0	3	1/1	3	334–130	233	1/1	236	239	33·5	
801	9. i	104–0	208	1/1	208	210–128	323	1/2	646	854	37·5	
802	10. i	126–0	652	1/10	6,520	320– 70	435	1/10	4,350	10,870	68·6	
803	10. i	120–0	564	1/32	18,048	308–130	475	1/4	1,900	19,984	49·2	
						Weddell Sea, Jan. 1932						
804	11. i	130–0	80	1/4	320	290–104	289	1/5	1,445	1,765	35·25	
806	12. i	116–0	37	1/2	74	216–144	515	1/2	1,030	1,104	54·6	
807	13. i	131–0	4	1/5	20	264– 84	100	1/5	500	520	15·0	
808	13. i	120–0	22	1/2	44	250–100	130	1/1	130	174	28·35	
809	14. i	128–0	25	1/5	125	196–104	95	1/1	95	220	5·8	
810	14. i	166–0	11	1/10	110	304–130	59	1/1	59	169	4·05	
811	15. i	112–0	22	1/20	440	—	—	—	—	—	(3·7)	
812	16. i	137–0	32	1/10	320	318–102	57	1/1	57	377	10·5	
813	16. i	135–0	42	1/4	168	340–100	63	1/5	315	483	7·8	
815	17. i	140–0	4	1/1	4	314–188	107	1/1	107	111	6·35	
816	18. i	133–0	4	1/10	40	256– 80	179	1/1	179	219	13·04	
817	19. i	132–0	7	1/4	28	260–162	176	1/1	176	214	9·5	
						Weddell Sea and Eastern Scotia Sea, Jan. 1932						
818	20. i	77–0	—	1/1	—	—	—	—	—	—	—	
819	20. i	105–0	1	1/1	1	—	—	—	—	—	—	
820	21. i	110–0	1	1/2	2	—	—	—	—	—	(0·12)	
822	23. i	146–0	164	1/4	656	244–130	22	1/1	22	678	18·9	
823	27. i	179–0	46	1/10	460	312–119	1	1/1	1	461	15·8	
824	27. i	157–0	20 44	1/10 1/1	244	300–104	85	1/2	170	414	13·6	
825	28. i	117–0	17	1/25	425	310–100	27	1/10	270	695	3·5	
						Falkland Islands to South Georgia, Feb. 1932						
828	17. ii	141–0	51	1/5	125	250–100	22	1/1	22	147	11·3	
829	18. ii	140–0	19	1/4	76	270– 84	177	1/1	177	272	20·0	
830	19. ii	117–0	391	1/20	7,820	256–140	550	1/1	550	8,470	66·1	←
831	20. ii	130–0	149	1/50	7,450	250–100	222	1/5	1,110	8,560	28·4	

Table III *b*. *Horizontal distribution of* Rhincalanus gigas *Falkland Sector*, 1932–3

St.	Date	Upper net				Lower net				Total catch	% of *R. gigas* in total Copepoda	Position of Antarctic convergence
		Depth (m.)	Number examined	Fraction examined	Estimated total	Depth (m.)	Number examined	Fraction examined	Estimated total			
	1932	Falkland Islands to Magellan Straits, Oct. 1932										
979	15. x	117–0	1	1/1	1	—	—	—	—	1	—	
		Western Drake Passage, Oct. 1932										
983	23. x	121–0	230*	1/5	1,150	300–80	296*	1/4	1,184	2,334	47·2	
984	24. x	99–0	119	1/1	119	240–100	292	1/1	292	411	39·5	
985	24. x	113–0	16	1/4	64	290–110	153	1/1	153	217	10·05	
986	25. x	102–0	20	1/1	20	244–114	177	1/2	354	374	45·5	
988	26. x	88–0	464	1/1	464	224–74	384	1/10	3,840	4,304	83·5	
990	27. x	96–0	129	1/1	129	276–100	552	1/2	1,104	1,233	87·3	←
992	28. x	99–0	97	1/1	97	270–110	542	1/5	2,710	2,807	59·6	
994	29. x	113–0	2	1/1	2	270–90	143	1/1	143	145	33·4	
995	30. x	125–0	2	1/1	2	320–120	40	1/1	40	42	—	
		Ice edge (Southern Drake Passage) and Bransfield Strait, Oct.–Nov. 1932										
996	30. x	100–0	—	1/1	—	350–90	76	1/1	76	76	40·8	
		0–5	4	1/1	4	—	—	—	—	4	—	
997	30. x	0–5	—	1/1	—	—	—	—	—	—	—	
		0–10	—	1/1	—	—	—	—	—	—	—	
999	31. x	0–5	—	1/1	—	—	—	—	—	—	—	
		151–0	48	1/1	48	—	—	—	—	48	—	
1000	1. xi	128–0	20	1/1	20	300–110	405	1/2	810	830	80·6	
1001	1. xi	95–0	533	1/1	533	230–?66	398	1/1	398	931	48·8	
1003	2. xi	115–0	1	1/1	1	—	—	—	—	1	—	
1004	5. xi	123–0	—	1/1	—	320–120	33	1/1	33	33	—	
1005	5. xi	109–0	—	1/1	—	300–100	6	1/1	6	6	7·7	
1006	5. xi	115–0	—	1/1	—	300–152	—	1/1	—	—	—	
1009	6. xi	155–0	1	1/1	1	300–120	31	1/1	31	32	—	
		Eastern Drake Passage and South Atlantic, Nov. 1932										
1011	6. xi	100–0	1	1/1	1	—	—	—	—	1	—	
1013	6. xi	93–0	—	1/1	—	314–140	2	1/1	2	2	1·35	
1014	7. xi	144–0	—	1/1	—	—	—	—	—	—	—	
1015	7. xi	128–0	630	1/8	5,040	350–120	257	1/10	2,570	7,610	85·25	
1017	8. xi	110–0	845	1/20	16,900	330–150	1135	1/5	5,675	22,575	91·8	
1019	9. xi	119–0	271	1/20	5,420	320–110	272	1/10	2,720	9,140	61·06	←
		South Atlantic, Nov. 1932										
1021	13. xi	120–0	279	1/20	5,580	315–150	186	1/4	744	6,324	68·6	
1023	16. xi	112–0	1161	1/4	4,644	318–130	395	1/2	790	5,434	59·9	
1025	17. xi	140–0	939	1/10	9,390	400–160	329	1/5	1,645	11,035	49·0	
		Western Scotia Sea and South Atlantic, Nov. 1932										
1027	18. xi	100–0	363	1/10	3,630	300–125	474	1/1	474	4,104	43·7	←
1029	19. xi	100–0	323	1/20	6,460	300–150	105	1/1	105	6,565	57·8	
1031	20. xi	149–0	277	1/8	2,216	370–104	221	1/1	221	2,437	67·9	
1033	21. xi	113–0	307	1/8	2,156	270–100	124	1/1	124	2,280	63·8	
1034	24. xi	165–0	82†	1/1	82	—	—	—	—	—	—	
1035	24. xi	100–0	8	1/1	8	274–116	13	1/1	13	21	6·1	

* Includes a few *R. nasutus*. † Of these the majority appeared dead.

Table III *b* (*cont.*)

St.	Date	Upper net: Depth (m.)	Upper net: Number examined	Upper net: Fraction examined	Upper net: Estimated total	Lower net: Depth (m.)	Lower net: Number examined	Lower net: Fraction examined	Lower net: Estimated total	Total catch	% of *R. gigas* in total Copepoda	Position of Antarctic convergence
	1932	Scotia Sea and South Atlantic (east of South Georgia), Nov.–Dec. 1932										
1038	25. xi	151–0	43	1/5	215	375–110	22	1/1	22	237	3·2	
1041	26. xi	84–0	21	1/4	84	250–100	5	1/1	5	89	4·1	
1044	27. xi	117–0	136 3	1/1 1/5	151	296–100	2	1/2	4	155	3·8	
1045	29. xi	100–0	10	1/10	100	256–100	13	1/1	13	113	2·45	
1047	30. xi	84–0	121	1/5	605	230– 86	68	1/1	68	673	14·25	
1048	30. xi	119–0	71	1/4	284	340–140	65	1/1	65	349	15·9	
1050	1. xii	103–0	146	1/4	584	295–104	113	1/1	113	697	24·5	
1052	2. xii	133–0	107	1/8	856	340–100	84	1/10	840	1,696	55·6	
1054	3. xii	98–0	142	1/10	1,420	250– 90	330	1/4	1,320	2,740	22·6	
1056	4. xii	100–0	339	1/8	2,712	340–150	739	1/1	739	3,451	40·7	
		South Georgia, Dec. 1932										
1063	11. xii	128–0	271	1/8	2,168	334–114	132	1/4	528	2,696	44·25	
1066	12. xii	94–0	299	1/20	5,980	276–105	338	1/4	1,352	7,332	75·8	
1073	13. xii	117–0	334	1/4	1,336	—	—	—	—	—	—	
1076	13. xii	110–0	403	1/8	3,224	270–100	303	1/4	1,212	4,436	62·7	
		Scotia Sea, Dec. 1932–Jan. 1933										
1083	30. xii	125–0	546	1/10	5,460	250–100	227	1/2	454	5,914	64·35	
1085	31. xii	146–0	456	1/4	1,824	250–125	399	1/2	798	2,622	87·1	
	1933											
1088	1. i	100–0	2	1/1	2	260–100	53	1/1	53	55	16·58	
		Bransfield Strait, Jan.–Feb. 1933										
1097	31. i	119–0	1	1/1	1	280–124	41	1/2	84	85	3·85	
1101	1. ii	153–0	—	1/1	—	250–100	27	1/1	27	27	3·8	
1108	4. ii	134–0	—	1/1	—	290–100	22	1/1	22	22	15·8	
1110	4. ii	135–0	2	1/1	2	—	—	—	—	2	—	
		Drake Passage, Feb. 1933										
1115	6. ii	119–0	—	1/1	—	315–130	144	1/1	144	144	35·3	
1116	7. ii	110–0	405	1/2	810	270–115	514	1/4	2,056	2,866	97·2	
1117	7. ii	119–0	260	1/4	1,040	320–120	344	1/4	1,376	2,416	84·5	←
1119	8. ii	100–0	12	1/1	12	330–100	34	1/2	68	80	3·56	
		South Atlantic, Feb. 1933										
1122	20. ii	70–0	284	1/1	284	190–115	86	1/1	86	370	53·35	
1123	20. ii	102–0	2	1/4	8	250–100	320	1/1	320	328	19·8	←
1125	21. ii	97–0	550	1/20	11,000	290–100	191	1/4	764	11,764	49·8	
1127	23. ii	100–0	277	1/20	5,540	260– 90	209	1/4	836	6,376	27·8	
1131	24. ii	100–0	365	1/10	3,650	250–106	275	1/4	1,100	4,750	40·9	
		Weddell Sea, March 1933										
1138	2. iii	132–0	10	1/10	100	335–100	55	1/4	220	320	6·28	
1140	3. iii	104–0	8	1/10	80	310–110	20 5	1/1 1/4	40	120	1·5	
1142	4. iii	93–0	—	1/20	—	260–110	252	1/5	1,260	1,260	11·05	
1144	5. iii	119–0	23	1/10	230	340–100	179	1/1	179	409	10·8	
1146	6–7. iii	104–0	11	1/5	55	290–110	30	1/1	30	85	4·45	
1148	9. iii	117–0	100	1/2	200	330–100	144	1/1	144	344	21·0	
1150	10. iii	91–0	59	1/4	236	270–100	111	1/1	111	347	18·0	
1152	10. iii	115–0	46	1/4	184	—	—	—	—	—	—	
1153	12. iii	117–0	13	1/5	65	365–140	15	1/1	15	80	3·46	
		South Atlantic, March 1933										
1161	19. iii	91–0	221	1/1	221	340–150	153	1/4	612	833	85·8	

Table III *c*. *Horizontal distribution of* Rhincalanus gigas
Circumpolar Cruise, February–October, 1932

St.	Date	Upper net: Depth (m.)	Upper net: Number examined	Upper net: Fraction examined	Upper net: Estimated total	Lower net: Depth (m.)	Lower net: Number examined	Lower net: Fraction examined	Lower net: Estimated total	Total catch	% of *R. gigas* in total Copepoda	Position of Antarctic convergence
	1932	South Georgia to Cape Town, Feb.–Mar. 1932										
833	22. ii	173–0	11	1/1	11	—	—	—	—	—	—	
834	23. ii	146–0	384	1/1	384	250–100	210	1/1	210	594	23·73	←
835	25. ii	115–0	—	1/1	—	—	—	—	—	—	—	
836	27. ii	102–0	20	1/1	20	250–100	25	1/1	25	45	20·15	
837	27. ii	125–0	—	1/10	—	250–100	—	1/5	—	—	—	
838	28. ii	137–0	—	1/10	—	250–100	6	1/1	6	6	0·3	
		Cape Town to Enderby Land, April 1932										
848	13. iv	117–0	—	1/4	—	270–166	7	1/10	70	70	4·06	
849	14. iv	71–0	—	1/1	—	210–125	1	1/1	1	1	0·32	
850	15. iv	100–0	57	1/4	228	254–110	155	1/1	155	383	20·1	←
851	17. iv	125–0	110	1/2	220	320–190	514	1/1	514	734	40·1	
852	18. iv	119–0	78	1/5	390	370–155	72	1/10	720	1,110	40·1	
853	19. iv	119–0	112	1/4	448	190–108	233	1/2	466	914	45·6	
854	20. iv	119–0	2	1/1	2	248–98	8	1/1	8	10	0·93	
855	20. iv	125–0	3	1/4	12	280–154	22	1/1	22	34	2·4	
		Enderby Land to Fremantle, April–May, 1932										
856	22. iv	89–0	3	1/5	15	224–120	209	1/1	209	214	11·84	
857	24. iv	130–0	33	1/5	165	262–140	850	1/1	850	1,015	49·25	
858	24. iv	88–0	18	1/5	90	264–130	351	1/1	351	441	32·45	
859	25. iv	100–0	22	1/2	44	210–140	708	1/1	708	752	38·15	
860	26. iv	119–0	2	1/20	40	300–100	183	1/4	732	772	27·25	
861	28. iv	109–0	2	1/5	10	254–110	182	1/1	182	192	15·6	
862	28. iv	102–0	8	1/10	80	220–98	299	1/4	1,196	1,276	43·36	
863	30. iv	90–0	5	1/25	125	200–82	161	1/1	161	286	20·6	
865	1. v	116–0	6	1/1	6	290–150?	23	1/1	23	29	4·67	
866	2. v	98–0	—	1/2	—	284–110	48	1/1	48	48	3·8	←
867	2. v	139–0	—	1/5	—	330–150	2	1/1	2	2	0·37	
		Fremantle to ice edge, May 1932										
883	23. v	89–0	38	1/1	38	210–90	132	1/1	132	170	35·2	←
884	25. v	122–0	1	1/1	1	270–90	25	1/1	25	26	14·36	
885	25. v	116–0	—	1/1	—	280–120	92	1/1	92	92	34·05	
886	26. v	133–0	4	1/1	4	302–100	44	1/1	44	48	20·35	
887	27. v	86–0	113	1/1	113	—	—	—	—	—	—	
		120–0	533	1/1	533	235–115	54	1/1	54	587	43·7	
		Ice edge to Melbourne, May–June 1932										
889	29. v	106–0	—	1/1	—	290–90	80	1/1	80	80	21·5	
890	29. v	98–0	1	1/1	1	260–91	83	1/1	83	84	17·5	
891	30. v	121–0	5	1/1	5	260–90	248	1/1	248	253	36·25	←

Table III *c* (*cont.*)

St.	Date	Upper net: Depth (m.)	Upper net: Number examined	Upper net: Fraction examined	Upper net: Estimated total	Lower net: Depth (m.)	Lower net: Number examined	Lower net: Fraction examined	Lower net: Estimated total	Total catch	% of *R. gigas* in total Copepoda	Position of Antarctic convergence
	1932					Melbourne to ice edge, June 1932						
903	20. vi	131–0	—	1/1	—	370–140	55	1/1	55	55	17·4	←
904	20. vi	104–0	—	1/1	—	330–130	123	1/1	123	123	35·15	
905	21. vi	114–0	1	1/1	1	320–128	5	1/1	5	6	25·5	
906	22. vi	140–0	2	1/1	2	386–142	42	1/1	42	44	31·43	
907	23. vi	—	—	—	—	290–110	24	1/1	24	—	—	
						Ice edge to New Zealand, June 1932						
911	23. vi	106–0	1	1/1	1	310–110	2	1/1	2	3	2·79	
919	25. vi	128–0	—	1/1	—	306–130	25	1/1	25	25	25·8	←
920	26. vi	123–0	—	1/1	—	320–100	11	1/1	11	11	5·25	
						South Pacific Ocean, Aug.–Oct. 1932						
945	3. ix	102–0	1	1/1	1	255– 80	—	1/1	—	1	2·15	
948	5. ix	115–0	1	1/1	1	310–132	1	1/1	1	2	0·77	
961	12. ix	109–0	—	1/1	—	325–144	26	1/1	26	26	11·4	←
962	14. ix	134–0	—	1/1	—	320–100	1	1/1	1	1	0·34	←
963	14. ix	117–0	1	1/1	1	320–128	—	1/1	—	1	0·57	
970	25. ix	141–0	1	1/1	1	380–110	3	1/1	3	4	—	
971	25. ix	117–0	1	1/1	1	340–120	—	1/1	—	1	—	
972	26. ix	128–0	2	1/1	2	300–128	3	1/1	3	5	3·5	←
973	27. ix	100–0	—	1/1	—	270–120	1	1/1	1	1	0·75	
974	28. ix	115–0	—	1/1	—	314–114	—	1/1	—	—	—	
975	29. ix	117–0	—	1/1	—	290–104	1	1/1	1	1	0·41	
976	30. ix	73–0	6	1/1	6	190– 84	21	1/1	21	27	5·0	
977	1. x	119–0	2	1/1	2	318–140	—	1/1	—	2	0·51	
978	2. x	117–0	25	1/10	250	290–108	74	1/2	148	398	13·0	

Table IV *a*. Rhincalanus gigas, *percentage of total catch taken in upper and lower* 1-*m. nets in the Falkland Sector during seasons* 1931–2 *and* 1932–3 (*excluding stations in Weddell Sea water*) *and in the Indian Ocean and Australian Sectors in April and May* 1932

Where the combined catch in both nets amounts to less than 250 individuals the figures are placed in brackets. Results shown diagrammatically in Fig. 12.

St.	Date	Upper net %	Lower net %
	November 1931		
725	17. xi	35·8	64·2
726	18. xi	85·6	14·4
727	18. xi	88·2	11·8
729	19. xi	15·8	84·2
731	20. xi	96·1	3·9
733	21. xi	72·3	27·7
735	22. xi	28·4	71·6
737	23. xi	65·4	34·6
739	24. xi	27·54	72·46
741	25. xi	30·3	69·7
743	26. xi	20·2	79·8
745	28. xi	75·1	24·9
746	28. xi	11·1	88·9
748	29. xi	47·6	52·4
750	30. xi	34·8	65·2
	December 1931		
751	1. xii	79·6	20·4
753	2. xii	10·8	89·2
755	3. xii	95·7	4·3
757	4. xii	1·97	98·03
759	5. xii	21·97	78·03
769	12. xii	81·9	18·1
774	16. xii	8·3	91·7
775	16. xii	96·6	3·4
776	17. xii	38·9	61·1
778	18. xii	92·4	7·6
788	18. xii	78·9	21·1
	January 1932		
796	7. i	32·9	67·1
802	10. i	60·0	40·0
803	10. i	95·2	4·8
	February 1932		
828	17. ii	92·0	8·0
829	18. ii	30·04	69·96
830	19. ii	93·4	6·6
831	20. ii	87·03	12·97
	October 1932		
984	24. x	28·9	71·1
985	24. x	29·5	70·5
986	25. x	5·3	94·7
988	26. x	10·8	87·9
990	27. x	10·46	89·54
992	28. x	3·4	96·6
994	29. x	1·4	98·6
	November 1932		
1000	1. xi	4·7	95·3
1001	1. xi	57·2	42·8
1015	7. xi	66·2	33·8
1017	7. xi	75·3	24·7
1019	9. xi	65·8	34·2
1021	13. xi	88·25	11·75
1023	16. xi	85·5	14·5
1025	17. xi	85·1	14·9
1027	18. xi	88·5	11·5
1029	19. xi	98·4	1·4
1031	20. xi	90·5	9·5
1033	21. xi	95·2	4·8
	December 1932		
1054	3. xii	51·8	48·2
1056	4. xii	78·6	21·4
1063	11. xii	80·3	19·7
1066	12. xii	81·5	18·5
1076	13. xii	72·7	27·3
	December 1932 (cont.)		
1083	30. xii	92·4	7·6
1085	31. xii	69·6	30·4
	February 1933		
1115	6. ii	—	(100)
1116	7. ii	28·3	71·7
1117	7. ii	43·0	57·0
1122	20. ii	76·7	23·3
1123	20. ii	—	100
1125	21. ii	93·5	6·5
1127	23. ii	86·8	13·2
	April 1932		
850	15. iv	59·5	40·5
851	17. iv	29·9	70·1
853	19. iv	49·01	50·99
856	22. iv	6·7	93·3
857	24. iv	16·25	83·75
858	24. iv	20·4	79·6
859	25. iv	5·8	94·2
860	26. iv	5·2	94·8
861	28. iv	(5·5)	(94·5)
862	28. iv	6·3	93·7
863	30. iv	43·7	56·3
	May 1932		
883	23. v	(22·3)	(77·7)
885	25. v	—	(100)
887	27. v	90·8	9·2
891	30. v	(2·0)	(98·0)
	June 1932		
904	20. vi	—	(100)

Table IV *b*. Rhincalanus gigas, *percentage of total catch taken in upper and lower* 1-*m. nets in Weddell Sea water during the seasons* 1931–2 *and* 1932–3

Where the combined catch in both nets amounts to less than 250 individuals the figures are placed in brackets. Results shown diagrammatically in Fig. 13.

St.	Date	Upper net %	Lower net %
	December 1931		
760	6. xii	(21·1)	(78·9)
761	8. xii	40·9	59·1
763	8. xii	(63·7)	(36·3)
765	9. xii	86·9	13·1
766	10. xii	85·3	14·7
768	11. xii	71·3	28·7
779	19. xii	17·5	82·5
780	19. xii	60·4	39·6
	January 1932		
795	6. i	(2·9)	(97·1)
797	7. i	(4·6)	(95·4)
798	8. i	—	(100)
799	8. i	(1·3)	(98·7)
804	11. i	18·5	81·5
806	12. i	6·7	93·3
	January 1932 (cont.)		
807	13. i	3·8	96·2
808	13. i	(25·2)	(74·8)
809	14. i	(56·8)	(43·2)
810	14. i	(65·1)	(34·9)
812	16. i	84·7	15·2
815	17. i	(3·6)	(96·4)
816	18. i	(18·25)	(81·75)
817	19. i	(13·7)	(86·3)
822	23. i	96·7	3·3
823	27. i	99·8	0·2
824	27. i	58·9	41·1
825	28. i	61·15	38·85
	November 1932		
1038	25. xi	(90·7)	(9·3)
1044	27. xi	(97·4)	(2·6)
	November 1932 (cont.)		
1045	29. xi	(88·4)	(11·6)
	January 1933		
1097	31. i	(1·2)	(98·8)
	February 1933		
1131	24. ii	76·8	23·2
	March 1933		
1138	2. iii	31·3	68·7
1140	3. iii	(13·8)	(86·2)
1142	4. iii	—	100
1144	5. iii	56·3	43·7
1146	6. iii	(64·7)	(35·3)
1148	9. iii	58·1	41·9
1150	10. iii	68·01	31·99
1153	12. iii	(81·2)	(18·8)

Table V *a*. Rhincalanus gigas, *adults. Percentage of males and females Falkland Sector*, 1931–2

Where the numbers are too small to give reliable percentages the figures are placed in brackets.

St.	Date	Upper net % ♀	Upper net % ♂	Lower net % ♀	Lower net % ♂	Total % ♀	Total % ♂
	1931						
725	17. xi	95·24	4·76	100	—	97·6	2·4
726	18. xi	100	—	100	—	100	—
727	18. xi	98·4	1·55	100	—	99·2	0·77
729	19. xi	98·04	1·96	96·0	4·0	97·02	2·98
731	20. xi	100	—	99·2	0·76	99·6	0·4
733	21. xi	97·2	2·8	87·0	13·0	92·1	7·9
735	22. xi	98·5	1·5	98·6	1·4	98·5	1·5
737	23. xi	100	—	93·03	6·97	96·5	3·5
739	24. xi	100	—	96·4	3·6	98·2	1·8
741	25. xi	98·6	2·4	96·2	3·75	96·9	3·1
743	26. xi	100	—	100	—	100	—
745	28. xi	100	—	91·3	8·7	95·6	4·3
746	28. xi	100	—	94·0	6·02	97·0	3·0
748	29. xi	98·2	1·76	91·1	8·9	95·5	4·4
751	1. xii	99·3	0·69	98·97	1·03	99·1	0·86
753	2. xii	90·0	10·0	94·3	5·7	92·2	7·8
755	3. xii	100	—	99·11	0·89	99·6	0·4
757	4. xii	100	—	97·04	2·96	98·5	1·5
759	5. xii	100	—	99·5	0·48	99·76	0·24
761	8. xii	100	—	95·1	4·9	97·5	2·5
763	8. xii	(97·7)	(2·3)	(59·3)	(40·7)	(78·5)	(21·5)
765	9. xii	97·7	2·3	46·9	53·1	72·3	27·7
766	10. xii	95·9	4·1	67·7	32·3	81·8	18·2
768	11. xii	96·0	4·0	38·3	61·7	67·2	32·8
774	16. xii	100	—	93·5	6·5	96·75	3·25
775	16. xii	97·4	2·6	50·8	49·2	74·1	25·9
776	17. xii	100	—	95·4	4·4	97·8	2·2
778	18. xii	100	—	83·2	16·8	91·6	8·4
	1931						
779	19. xii	100	—	94·5	5·5	97·2	2·75
780	20. xii	100	—	98·05	1·95	99·03	0·97
788	21. xii	99·4	0·6	87·3	12·7	93·3	6·7
	1932						
795	6. i	100	—	100	—	100	—
796	7. i	100	—	99·6	0·4	99·8	0·20
798	8. i	100	—	100	—	100	—
802	10. i	100	—	90·8	9·2	95·4	4·6
804	11. i	96·0	4·0	96·7	3·3	96·3	3·7
806	12. i	100	—	100	—	100	—
807	13. i	—	—	(95·8)	(4·2)	(95·8)	(4·2)
808	13. i	—	—	91·9	8·1	—	—
809	14. i	100	—	100	—	100	—
810	14. i	(87·5)	(12·5)	(95·5)	(4·5)	(91·5)	(8·5)
812	16. i	(100)	—	(91·2)	(9·6)	(95·2)	(4·8)
815	17. i	—	—	(70·9)	(29·1)	(85·5)	(14·5)
816	18. i	(100)	—	(100)	—	(100)	—
817	19. i	(100)	—	(50·0)	(50·0)	(75·0)	(25·0)
822	23. i	92·96	7·04	(86·7)	(13·3)	89·8	10·17
823	27. i	100	—	—	—	100	—
824	27. i	100	—	—	—	100	—
825	28. i	100	—	(91·7)	(8·3)	95·9	4·1
828	17. ii	—	—	—	—	—	—
829	18. ii	—	—	(33·4)	(66·6)	(33·4)	(66·6)
830	19. ii	97·6	2·4	90·8	9·2	94·2	5·8
831	20. ii	—	—	—	—	—	—
834	23. ii	—	—	92·0	8·0	92·0	8·0

Table V *b*. Rhincalanus gigas, *adults. Percentage of males and females Falkland Sector*, 1932–3

Where the numbers are too small to give reliable percentages the figures are placed in brackets.

St.	Date	Upper net %		Lower net %		Total %	
		♀	♂	♀	♂	♀	♂
	1932						
978	2. x	100	—	97·0	3·0	98·5	1·5
984	24. x	98·0	2·0	93·4	6·6	95·5	4·5
1000	1. xi	—	—	98·7	1·3	98·7	1·3
1004	5. xi	—	—	(100)	—	(100)	—
1005	5. xi	—	—	—	—	—	—
1006	5. xi	—	—	—	—	—	—
1009	6. xi	—	—	(100)	—	(100)	—
1011	6. xi	—	—	—	—	—	—
1015	7. xi	94·9	5·08	88·7	11·3	91·8	8·2
1019	9. xi	100	—	91·1	8·9	95·5	4·5
1021	13. xi	97·7	2·3	81·5	18·5	89·6	10·4
1029	19. xi	98·9	1·1	—	—	—	—
1031	20. xi	97·2	2·8	98·9	1·1	98·05	1·95
1033	21. xi	98·7	1·3	75·0	25·0	86·8	13·1
1041	26. xi	100	—	(100)	—	100	—
1045	29. xi	100	—	(87·5)	(12·5)	(93·7)	(6·3)
1048	30. xi	100	—	—	—	—	—
1050	1. xii	88·8	1·12	—	—	—	—
1052	2. xii	96·4	3·6	26·9	73·1	61·6	38·4
1054	3. xii	98·0	2·0	57·2	42·8	77·6	22·4
1056	4. xii	98·8	1·2	—	—	—	—
1063	11. xii	98·7	1·3	48·9	51·1	73·8	26·2
1066	12. xii	98·7	1·3	64·2	35·8	81·4	18·6
1073	13. xii	95·5	4·5	—	—	—	—
1076	13. xii	93·8	6·4	82·0	18·0	87·9	12·1

St.	Date	Upper net %		Lower net %		Total %	
		♀	♂	♀	♂	♀	♂
	1932						
1083	30. xii	99·03	0·97	67·5	32·5	83·3	16·7
1085	31. xii	99·6	0·4	94·8	5·4	97·2	2·9
	1933						
1088	1. i	(100)	—	(100)	—	(100)	—
1097	31. i	(100)	—	(100)	—	(100)	—
1101	1. ii	—	—	(100)	—	—	—
1108	4. ii	—	—	(100)	—	(100)	—
1115	6. ii	—	—	93·4	6·6	93·4	6·6
1116	7. ii	100	—	100	—	100	—
1117	7. ii	97·8	2·2	98·2	1·8	98·0	2·0
1119	8. ii	—	—	—	—	—	—
1122	20. ii	(90·3)	(9·7)	(100)	—	95·1	4·9
1123	20. ii	—	—	(78·8)	(21·4)	(78·8)	(21·4)
1125	21. ii	100	—	95·3	4·7	97·6	2·4
1127	23. ii	100	—	100	—	100	—
1131	24. ii	100	—	97·0	3·0	98·5	1·5
1138	2. iii	(100)	—	(94·5)	(5·5)	(97·2)	(2·8)
1140	3. iii	(100)	—	(100)	—	(100)	—
1142	4. iii	—	—	—	—	—	—
1144	5. iii	(100)	—	92·9	7·1	96·4	3·6
1146	6. iii	—	—	(100)	—	(100)	—
1148	9. iii	(93·3)	(6·7)	(77·8)	(22·2)	(85·5)	(15·15)
1150	10. iii	(100)	—	(100)	—	(100)	—
1152	10. iii	(100)	—	—	—	—	—
1153	12. iii	(87·5)	(12·5)	(75·0)	(25·0)	(81·2)	(8·8)

Table V *c*. Rhincalanus gigas, *adults. Percentage of males and females Circumpolar Cruise, April–June* 1932

Where the numbers are too small to give reliable percentages the figures are placed in brackets.

St.	Date	Upper net %		Lower net %		Total %	
		♀	♂	♀	♂	♀	♂
	1932						
850	15. iv	100	—	98·8	1·2	99·4	0·6
851	17. iv	(100)	—	97·1	2·9	98·5	1·5
853	19. iv	100	—	98·7	1·3	99·3	0·7
855	20. iv	—	—	—	—	—	—
856	22. iv	—	—	97·3	2·7	97·3	2·7
858	24. iv	—	—	(100)	—	(100)	—
860	26. iv	—	—	(100)	—	(100)	—
862	28. iv	—	—	(100)	—	(100)	—
884	24. v	—	—	—	—	—	—
887	27. v	—	—	—	—	—	—

St.	Date	Upper net %		Lower net %		Total %	
		♀	♂	♀	♂	♀	♂
	1932						
889	29. v	—	—	—	—	—	—
890	29. v	—	—	—	—	—	—
891	29. v	—	—	—	—	—	—
903	19. vi	—	—	—	—	—	—
904	20. vi	—	—	(100)	—	—	—
906	22. vi	—	—	(100)	—	—	—
907	23. vi	—	—	—	—	—	—
911	23. vi	—	—	—	—	—	—
919	25. vi	—	—	—	—	—	—

Table VI *a*. Rhincalanus gigas. *Percentage of nauplii* (*N*) *and of copepodite stages* (*i–vi*) *Drake Passage and South Atlantic Ocean*, *November* 1931 (Fig. 19)

St.	Date 1931	Upper net							Lower net						
		N	i	ii	iii	iv	v	vi	N	i	ii	iii	iv	v	vi
		Western Drake Passage (Magellan Straits to ice edge)													
725	17. xi	—	—	—	—	—	80·0	20·0	—	—	—	—	3·3	54·3	42·3
726	18. xi	—	—	—	—	3·6	56·0	36·5	—	—	—	—	1·8	57·3	40·8
727	18. xi	—	—	—	—	2·5	33·6	63·8	—	—	—	0·7	2·9	76·5	21·3
729	19. xi	—	—	—	5·9	42·9	32·6	18·5	—	—	—	1·25	36·8	33·5	28·4
731	20. xi	—	—	—	0·9	40·7	46·5	8·3	—	—	—	3·1	35·2	32·8	28·7
733	21. xi	—	—	—	1·6	35·2	49·1	13·99	—	—	—	4·04	35·4	35·6	24·8
		Ice edge (Southern Drake Passage)													
735	22. xi	—	—	—	0·96	10·9	46·3	41·74	—	—	2·5	22·5	35·2	22·1	17·55
737	23. xi	—	—	0·4	4·7	21·2	45·9	27·8	—	—	2·04	14·8	30·8	36·3	15·9
739	24. xi	—	—	0·8	4·2	17·03	54·5	23·5	—	—	0·15	6·6	29·4	46·8	22·6
741	25. xi	—	—	—	0·7	12·9	57·2	29·3	—	—	—	5·6	24·2	45·3	24·8
		Eastern Drake Passage and South Atlantic													
743	26. xi	—	—	—	4·1	31·8	33·5	11·2	—	—	—	3·8	23·4	52·5	20·3
745	28. xi	—	—	—	3·0	29·0	58·5	9·5	—	—	0·24	3·6	18·7	46·7	30·6
746	28. xi	—	—	—	3·7	40·0	50·0	6·05	—	—	—	0·90	13·0	56·1	29·9
748	29. xi	—	—	—	1·8	37·3	45·7	15·26	—	—	—	2·7	29·8	37·9	29·5
750	30. xi	—	—	—	0·5	10·7	52·1	36·5	—	—	—	0·28	20·7	31·4	47·6

Table VI *b*. Rhincalanus gigas. *Percentage of nauplii* (*N*) *and of copepodite stages* (*i–vi*) *Scotia Sea and South Georgia*, *December* 1931 (Fig. 20)

When percentages are based on less than 100 specimens the figures are bracketed.

St.	Date 1931	Upper net							Lower net						
		N	i	ii	iii	iv	v	vi	N	i	ii	iii	iv	v	vi
		Western Scotia Sea and South Atlantic													
751	1. xii	—	—	—	—	10·1	52·1	37·66	—	—	—	—	10·9	42·8	46·3
753	2. xii	—	—	—	—	8·86	80·72	10·44	—	—	—	0·12	31·5	60·7	6·7
755	3. xii	—	—	—	—	13·0	53·8	32·4	—	—	—	2·8	20·2	48·2	34·0
757	4. xii	—	—	—	—	(10)	(80)	(10)	—	—	—	1·2	38·2	53·3	27·2
759	5–6. xii	—	—	—	8·4	27·05	46·7	17·75	—	—	—	0·26	8·7	36·9	54·16
		Eastern Scotia Sea													
761	7. xii	—	—	—	2·7	23·0	52·8	21·3	—	—	—	—	20·4	35·2	52·0
763	8. xii	—	—	—	—	3·2	26·8	69·1	—	—	—	—	28·5	32·8	38·5
765	9. xii	—	—	—	—	2·8	24·1	73·0	—	—	—	0·63	7·4	46·8	44·9
766	10. xii	—	—	—	—	3·38	27·6	66·8	—	—	—	—	9·0	23·0	68·0
768	11. xii	—	—	—	1·1	—	14·65	84·2	—	—	—	—	0·28	28·9	70·9
		South Georgia													
774	16. xii	—	—	—	—	1·1	66·3	32·6	—	—	—	—	1·69	49·9	48·35
775	16. xii	—	—	0·25	0·5	2·2	53·3	42·5	—	—	—	—	11·6	39·0	49·2
776	17. xii	—	—	—	3·4	46·8	27·2	22·4	—	—	—	—	18·4	34·8	44·6
788	21. xii	—	—	—	0·15	2·65	50·0	47·05	—	—	—	—	2·26	37·4	60·0

Table VI *c*. Rhincalanus gigas. *Percentage of nauplii* (*N*) *and of copepodite stages* (*i–vi*) *South Atlantic and Weddell Sea, December* 1931–*January* 1932 (Figs. 21–23)

St.	Date 1931–2	Upper net							Lower net						
		N	i	ii	iii	iv	v	vi	N	i	ii	iii	iv	v	vi
		Bellingshausen Sea current													
778[1]	18. xii	4·3	6·1	13·4	4·3	1·8	33·5	36·5	—	—	—	—	6·6	30·1	63·2
796[1]	7. i	—	—	13·0	80·1	5·3	1·36	0·21	—	—	—	7·4	25·6	15·5	49·50
802[1]	10. i	—	—	—	34·2	48·4	4·8	12·4	—	—	6·1	76·1	17·0	—	0·92
803[1]	10. i	—	—	3·37	58·9	33·7	1·23	1·57	—	—	—	39·4	22·0	7·1	31·5
		Weddell Sea													
779[2]	19. xii	—	—	—	1·5	7·7	31·1	59·6	—	—	—	—	11·4	28·9	64·0
795[2]	6. i	Numbers insignificant							—	—	—	1·0	16·8	46·5	35·1
798[2]	8. i	,, ,,							—	—	—	1·9	24·0	55·9	18·3
806[2]	12. i	,, ,,							—	—	—	1·9	30·9	53·7	13·4
808[2]	13. i	,, ,,							—	—	—	0·78	22·2	48·4	28·4
780[3]	19. xii	—	—	—	—	1·2	22·8	75·9	—	—	—	—	3·0	17·3	78·7
804[3]	11. i	—	—	—	6·25	32·5	30·0	32·5	—	—	—	1·7	15·1	30·3	52·4
807[3]	13. i	Numbers insignificant							—	—	—	—	18·0	34·0	48·0
809[4]	14. i	,, ,,							—	—	—	1·05	11·6	34·7	52·6
810[4]	14. i	,, ,,							—	—	—	8·5	6·8	10·2	74·6
812[4]	16. i	—	—	—	—	3·1	9·35	87·5	—	—	—	1·75	5·25	1·75	91·15
816[5]	18. i	Numbers insignificant							—	—	—	1·7	64·2	34·0	—
817[5]	19. i	,, ,,							—	—	—	17·0	65·3	16·4	1·12
822[6]	23. i	—	—	—	—	0·6	12·9	86·6	Numbers insignificant						
823[6]	27. i	—	—	—	—	—	8·6	91·3	,, ,,						
824	27. i	—	—	—	0·29	6·17	82·6	10·2	—	—	—	—	2·3	42·3	55·2
825	28. i	—	—	17·6	76·4	—	—	5·9	—	—	3·7	25·9	7·4	18·5	44·4

[1] Average temp., 0–100 m., 1–3·0° C.
[2] Average temp., 0–100 m., 0–1·0° C.
[3] Average temp., 0–100 m., −1·0–0° C.
[4] Average temp., 0–100 m., < −1·0° C.
[5] Average temp., 0–100 m., < −1·0° C. East wind drift current.
[6] Average temp., 0–100 m., < −1·5° C.

Table VI *d*. Rhincalanus gigas. *Percentage of nauplii* (*N*) *and of copepodite stages* (*i–vi*) *Falkland Islands to South Georgia, mid-February* 1932 (Fig. 24)

When percentages are based on less than 100 specimens the figures are bracketed.

St.	Date 1932	Upper net							Lower net						
		N	i	ii	iii	iv	vi	vi	N	i	ii	iii	iv	v	vi
828	17. ii	—	—	(21·6)	(78·4)	—	—	—	Numbers insignificant						
829	18. ii	Numbers insignificant							—	—	—	75·1	12·3	9·03	3·33
830	19. ii	—	—	7·4	16·6	26·82	27·6	21·51	—	—	—	6·9	28·7	42·7	21·6
831	20. ii	—	—	4·02	55·7	35·5	3·9	0·65	—	—	9·0	37·4	55·0	4·6	2·3
834	23. ii	—	—	—	7·3	17·7	15·1	59·9	—	—	—	14·76	15·7	15·7	52·3

Table VI *e*. Rhincalanus gigas. *Percentage of nauplii* (*N*) *and of copepodite stages* (*i–vi*) *South Indian Ocean and Australian Sector. Winter months, April, May, June* 1932 (Fig. 25)

St.	Date 1932	Upper net							Lower net						
		N	i	ii	iii	iv	v	vi	N	i	ii	iii	iv	v	vi
						Cape Town to Enderby Land									
850	15. iv	—	—	—	17·5	35·1	24·5	22·8	—	—	—	0·6	9·7	37·4	52·2
851	17. iv	—	—	1·8	42·7	40·0	13·6	1·8	—	—	0·02	13·8	35·7	36·6	12·8
853	19. iv	—	—	—	—	20·5	53·5	25·9	—	—	—	—	27·9	39·4	32·6
						Enderby Land to Fremantle									
856	22. iv	Numbers insignificant							—	—	—	2·7	37·3	58·9	0·9
858	24. iv	,, ,,							—	—	—	5·1	38·7	52·4	3·7
860	26. iv	,, ,,							—	—	—	7·6	43·1	45·3	3·8
862	28. iv	,, ,,							—	—	—	25·7	34·8	35·75	3·7
						Ice edge to Melbourne									
887	27. v	10·3	10·1	58·9	20·6	—	—	—	—	—	5·4	38·8	9·0	46·3	—
891	30. v	Numbers insignificant							—	—	—	75·8	22·1	20·2	—
						Melbourne to ice edge									
904	20. vi	Numbers insignificant							—	—	—	32·5	44·3	20·1	2·4

Table VI *f*. Rhincalanus gigas. *Percentage of nauplii* (*N*) *and of copepodite stages* (*i–vi*) *Drake Passage, October–mid-November* 1932 (Fig. 26)

When percentages are based on less than 100 specimens the figures are bracketed.

St.	Date 1932	Upper net							Lower net						
		N	i	ii	iii	iv	v	vi	N	i	ii	iii	iv	v	vi
						Western Drake Passage (Magellan Straits to ice edge)									
978	2. x	—	—	—	—	(48·0)	(16·0)	(36·0)	—	—	—	12·2	18·9	24·4	44·5
984	24. x	—	—	—	0·84	11·6	44·5	42·04	—	—	—	—	15·4	17·1	67·4
988	26. x	—	—	—	4·5	38·6	20·9	36·5	—	—	—	1·8	11·2	10·7	76·3
990	27. x	—	—	—	5·4	54·2	19·4	20·9	—	—	—	2·3	22·0	16·4	58·96
992	28. x	—	—	—	—	14·4	31·9	53·6	—	—	—	3·7	18·4	39·8	44·6
994	29. x	None							—	—	—	2·1	30·0	34·8	32·8
						Southern Drake Passage									
1000	1. xi	Numbers insignificant							—	—	—	1·4	23·9	36·5	37·8
						Eastern Drake Passage									
1015	7. xi	—	—	—	0·1	8·5	53·7	37·4	—	—	—	—	14·8	50·9	34·2
1019	9. xi	—	—	—	—	4·3	45·7	49·8	—	—	—	0·7	19·6	46·4	33·3

Table VI *g*. Rhincalanus gigas. *Percentage of nauplii* (*N*) *and of copepodite stages* (*i–vi*) *Scotia Sea and South Atlantic, mid-November–December* 1932 (Fig. 27)

St.	Date 1932	Upper net N	i	ii	iii	iv	v	vi	Lower net N	i	ii	iii	iv	v	vi
								South Atlantic							
1021	13. xi	—	—	—	—	14·6	69·8	15·4	—	—	—	—	4·7	66·1	29·0
								Western Scotia Sea							
1029	19. xi	—	—	—	0·32	6·8	37·8	35·9	—	—	—	—	—	—	—
1031	20. xi	—	—	—	0·36	5·1	17·7	74·92	—	—	—	—	0·9	16·3	82·3
1033	21. xi	—	—	—	0·3	4·17	19·2	76·17	—	—	—	—	4·0	21·8	74·1
								Scotia Sea and South Atlantic (east of South Georgia)							
1048	30. xi	—	—	—	—	5·6	28·1	66·2	—	—	—	—	—	—	—
1050	1. xii	—	—	—	0·68	8·9	29·5	60·98	—	—	—	—	—	—	—
1052	2. xii	—	—	—	—	—	48·6	51·4	—	—	—	—	2·4	23·8	61·9
1054	3. xii	—	—	—	3·5	0·7	26·74	69·0	—	—	1·2	5·1	0·61	27·8	65·1
1056	4. xii	—	—	—	5·6	1·47	18·5	74·28	—	—	—	—	—	—	—
								South Georgia							
1063	11. xii	—	—	—	—	—	19·91	80·06	—	—	—	—	2·15	32·5	65·1
1066	12. xii	—	—	—	—	—	21·1	78·9	—	—	—	0·9	9·2	32·0	68·6
1073	13. xii	—	—	—	—	0·3	20·1	79·5	—	—	—	—	—	—	—
1076	13. xii	—	—	—	—	5·0	22·0	77·4	—	—	—	—	2·5	22·1	75·2
								Scotia Sea							
1083	30. xii	—	—	—	—	—	24·3	75·6	—	—	—	—	—	32·1	67·8
1085	31. xii	—	—	—	0·2	—	43·2	56·5	—	—	—	—	—	20·8	79·2

Table VI *h*. Rhincalanus gigas. *Percentage of nauplii* (*N*) *and of copepodite stages* (*i–vi*) *Drake Passage and South Atlantic, February* 1933 (Fig. 28)

St.	Date 1933	Upper net N	i	ii	iii	iv	v	vi	Lower net N	i	ii	iii	iv	v	vi
								Drake Passage							
1115	6. ii				None				—	—	—	—	32·0	15·9	52·0
1116	7. ii	—	—	—	0·49	40·4	45·6	12·3	—	—	—	0·72	57·6	33·3	7·6
1117	7. ii	—	—	0·76	1·5	0·38	62·3	34·96	—	—	—	—	0·3	62·3	48·6
								South Atlantic							
1122	20. ii	—	—	0·10	12·3	37·0	38·7	9·95	—	—	—	2·3	61·5	26·7	9·3
1123	20. ii				Numbers insignificant				—	—	—	50·6	23·5	21·5	4·3
1125	21. ii	—	—	—	12·3	18·7	43·8	25·2	—	—	—	9·4	32·0	25·1	33·5
1127	23. ii	—	—	—	40·0	44·0	8·3	7·6	—	—	—	36·3	43·0	6·2	14·3
1131	24. ii	—	—	0·3	39·4	55·6	—	4·6	—	—	0·35	31·6	35·9	8·4	24·0

Table VI *i*. Rhincalanus gigas. *Percentage of nauplii* (N) *and of copepodite stages* (*i–vi*)
Weddell Sea and South Atlantic, March 1933 (Fig. 29)

St.	Date 1933	Upper net							Lower net						
		N	i	ii	iii	iv	v	vi	N	i	ii	iii	iv	v	vi
								Weddell Sea							
1138	2. iii	—	—	—	20·0	50·0	20·0	10·0	—	—	—	16·4	38·2	12·6	32·7
1142	4. iii				None				—	—	0·8	19·04	77·0	3·2	—
1144	5. iii	—	—	4·3	43·0	30·1	17·2	4·3	—	—	—	7·8	26·2	50·2	15·7
1148	9. iii	—	—	—	—	34·0	51·0	15·0	—	—	—	2·1	2·8	82·6	12·5
1150	10. iii	—	—	—	—	42·4	76·2	11·8			Numbers insignificant				
1152	10. iii	—	—	—	—	26·0	50·0	23·9	—	—	—	—	—	—	—
								South Atlantic							
1161	19. iii	—	—	—	0·45	22·6	73·9	3·2	—	—	—	—	5·2	61·4	33·3

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